(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 0 774 681 A1

(12) **EUROPEAN PATENT APPLICATION**
published in accordance with Art. 158(3) EPC

(43) Date of publication:
21.05.1997 Bulletin 1997/21

(21) Application number: **96916314.6**

(22) Date of filing: **05.06.1996**

(51) Int. Cl.[6]: **G02B 26/10**

(86) International application number:
PCT/JP96/01520

(87) International publication number:
WO 96/39643 (12.12.1996 Gazette 1996/54)

(84) Designated Contracting States:
DE FR GB

(30) Priority: **05.06.1995 JP 138081/95**
05.06.1995 JP 138082/95
15.06.1995 JP 148811/95

(71) Applicant: **Nihon Shingo Kabushiki Kaisha**
Tokyo 100 (JP)

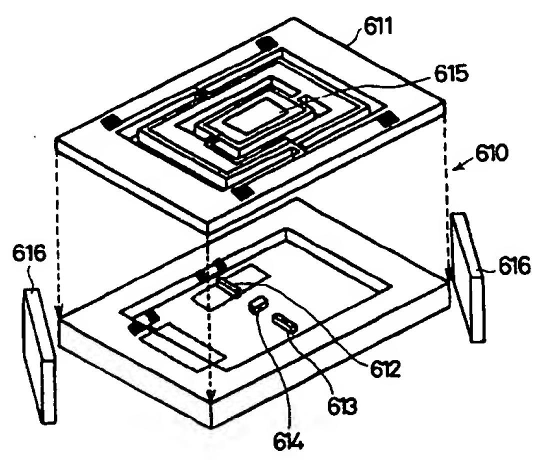
(72) Inventor: **ASADA, Norihiro,**
Nihon Shingo Kabushiki Kaisha
Urawa-shi, Saitama-ken 338 (JP)

(74) Representative: **Klocke, Peter, Dipl.-Ing.**
Patentanwälte Dipl.-Ing. Elmar Ott,
Dipl.-Ing. Peter Klocke,
Dipl.-Phys. Hans-J. Neubauer,
Kappelstrasse 8
72160 Horb (DE)

(54) ELECTROMAGNETIC ACTUATOR

(57) An electromagnetic actuator for driving a movable plate equipped with an optical element such as a mirror on the basis of the operation principle of a galvanometer. The structure of the movable plate is simplified, and a driving coil and a wiring are formed by aluminium vapor deposition to improve durability. When an impact brings the movable plate outside the allowable rocking range of the movable plate, a stopper prevents excessive displacement of the movable plate to thereby prevent destruction of a torsion bar that supports the movable plate. Moreover, electrical connection in the torsion bar is eliminated to prolong the service life, and a production process is simplified to reduce a production cost.

FIG.9



EP 0 774 681 A1

BEST AVAILABLE COPY

BNSDOCID: <EP___0774681A1_I_>

Description

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to an electromagnetic actuator based on the operation principle of "galvano-miller" manufactured by utilizing the "semiconductor manufacturing process" which is the process for manufacturing semiconductor devices, such as transistors or integrated circuits.

2. Brief Description of the Related Art

Examples of electromagnetic actuators of such a type are disclosed in Japanese laid-open publication Nos. 5-320524, 6-9824 6-310657 and 6-327569.

Disclosed in Japanese laid-open publication Nos. 5-320524 is a fundamental model of an electromagnetic actuator of this type, comprising a semiconductor substrate, on which a movable plate and a torsion bar are integrally mounted, wherein the torsion bar swingably supporting the movable plate with respect to the substrate, a driving coil formed around the movable plate, a galvano-miller mounted to the movable plate, and means for generating a magnetic field for applying a magnetic field for the driving coil; and the movable plate is driven by the galvano-miller by flowing a current through the driving coil.

Laid-open publication No. 6-9824 discloses substantially the fundamental model as described above, but modified in that a detection coil for positional detection of the movable plate is connected to the driving coil.

Laid-open publication No. 6-310657 discloses an optical detector of the type in which the direction of the optical axis is variable, wherein the miller in the galvano-miller disclosed in No. 5-320524 or No.6-9824 is replaced by a photo-dedector element.

Finally, Laid-open publication No. 6-327369 discloses an electro magnetic actuator of the type, such as galvano-miller or optical axis variable type, in which a torsion bar is made of electro-conductive to form an electric connection, so as to prevent disconnection of the wiring pattern around the torsion bar caused by the repetion of torsional action of the torsion bar.

The electromagnetic actuator disclosed in Laid-open publication No. 6-310657 is described below as to the embodiment thereof

RELATED ART 1

With reference to enlarged views of FIGS.32 and 33, as the related art 1, the arrangement of "an optical detector of the type in which the direction of the optical axis is varable" is described. The example s of the related arts 1 to 3 hereinafter are all of the type which operates by the same principle of the galvanometer. Also, the drawingss includeing FIGS. 34 to 39 are all enlarged views.

In FIGS. 32 and 33, the optical detector 1 of the type in which the direction of the optical axis is varable is composed of a three-layered structure, including a silicone base 2 as a semiconductor substrate, and a pair of borosilicate glass bases 3 and 4 bonded on the upper and lower surfaces of the silicone base. laminated so as to allow free outside.

Here, there is the Joule's loss due to the resistance component in the coil, and sometimes the driving ability is limited due to generat ed heat, and, therefore, the flat coil 7 is formed by electroforming, co mprising the steps of: sputtering a thin nickel layer on a substrate, fo rming thereon a copper layer by Cu electrolytic plating, and removing pa rt of Cu and Ni layer leaving the coil pattern to form the flat coil, fe atured in forming the thin layer coil with low resistance and high densi ty, providing the micromagnetic device with miniturlized and thinned pro file.

On the upper central area of the coil, a pn photodiode 8 is form ed in a known process, and a pair of electrode terminals 9, 9 connecting to the flat coil 7 via the portion of torsion bar 6, where the terminal s 9, 9 are formed simultaneously with forming of the flat coil 7.

On both sides referring to FIG.32 of substrates 3 and 4, each pair-formed annular permanent magnets 10A, 10B; and 11A, 11B for applying a magnetic field on the flat coil, on the region parallel with the torsion bar axis. Three pairs of magnets 10A, 10B, each pair therein being vertically arranged, are located such that the polarity is uniform , e.g. all N-poles locate lower sides, and S-poles upper sides as in FIG .33. Similarly, the other three pairs 11A, 11B are located so as to have the polarity opposite to the above-mentioned pairs 10A and 10B.

Also, on the lower side of the glass base 4, a pair of coils are patterned and provided, which are connected to the paired terminals 13 and 14 (Schematically depicted by one dotted line in FIG. 32, but actually of a plurality of turns). The detection coils 12A, 12B are located symmetrically relative to torsion bar 6, to detect the displacement angle of movable plate 5, and are located so that the mutual inductance between the flat coil 7 and detection coils 12A, 12B varies so as to increase when one of these approaches the other, and decrease when the other is away from the other. For example, by detecting the change of the voltage signal produced due to the mutual inductance, the displacement angle of movable plate 5 can be detected.

In operation, when a current is flowed across one terminal 9 and the other 9 as + and - electodes, respectively, a magnetic field is formed so as to cross the flat coil 7 as the arrow B in FIG.34 shows. When a current flows via the coil 7, a force F is applied on flat coil 7 , or, in other words, across the ends of movable plate 5, in the direction according to the Flemming's left-hand law, and such a force is obtained by the Lorentz' law.

The force F is obtained by the following formula (1), when i is current density flowing across the coil 7, and B

BNSDOCID: <EP___0774681A1_I_>

is magnetic flux formed by the upper and lower magnets:

$$F = i \cdot B \quad (1)$$

Actually, depending on the turn number n of coil 7, and the coil length w along which the force F is applied, the force F is again:

$$F = nw (i \cdot B) \quad (2)$$

On the other hand, by rotation of movable plate 5, the torsion bar 6 is tilted, and relation between the opposed spring force F' and the displacement angle ϕ of movable plate 5 is as follows:

$$\phi = (Mx / Gip) = (F'L/8.5 \cdot 109\ r4) \cdot 11 \quad (3)$$

Where Mx: torsional moment, G: lateral elastic coefficient, Ip: polar sectional secondary moment. L, 11 and r are, respectively, the distance from the central axis to the force point, the length of the torsion bar , and the radius of torsion bar as shown in FIG.34.

As the movable plate 5 rotates until where the forces F and F' reach to their balanced state, the displacement angle varies in proportional with the current "i".

By controlling the current flowing via the coil 7, the object being monitored can be traced in the one-dimensional manner.

The induced voltage generated in detection coils 12A and 12B varies according to the displacement of optical detector element 8: thereby the detection of such voltage allows to detect the optical axis displacement angle ϕ of the detector element 8.

Also, by the arrangement in FIG. 35 as including a differential amplifier circuit, the optical axis displacement angle ϕ can be controlled in a precisioned manner.

In the above-describe Related art, the movalbe assembly can be typically small-sized and light-weighted. No compensation for the dispersion of component parts is required.

RELATED ART 2

An "optical axis direction variable-type photo-detector" shown in FIG.36, compared with the Related art 1, a two-axised photo-detector is provided, having a pair of torsion bars perpendicular with each other .

In FIG.36 again, the optical axis direction variable-type photodetector 21, having the three layered construction, includes a silicon s ubstrate 2 and a pair of upper and lower glass substrates 3, 4 bonded to gether. On each center of substrates 13 and 14, a pair of rectilinear r ecesses 3A, 3B are formed. The glass substrates 13, 14 each is bonded on the silicon substrate 2 in the manner that the upper glass 3 is placed on the Si substrate 2 with the recess 3A being lower side to be bonded thereon, while the lower glass 4 is placed with the recess 4A being upper side to be bonded on Si substrate 2. As a result, a space is provided, in which the movable plate 5 having a detection element 8 thereon is allowed to rock therein.

In operation, a current flowed across the coil 7A causes the ext ernal movable plate 5A to rotate around the first torsion bars 6A, 6A ac cording to the current direction, wherein the internal movable plate 5B also rotates integrally with the external movable plate 5A, and the phot odiode 8 operates in the same manner as the case of the Related art 1.

The object to be monitored can be traced in the two-dimensional manner.

RELATED ART 3

As shown in FIG.37, 38 and 39, an optical axis direction variable-type photo-detector is provided. Different from the Related art 2, either of glass substrates 3, 4 is formed in a flat shape having no recesses 3A, 4A. Instead, a rectilinear opening 3a is formed in the movable plate 3 for allowing the detection light to directly enter the photodiode 8.

VARIATIONS

Other variations are possible for the optical detector element instead of a photodiode, such as a line sensor or an area sensor, each comprising a plurality of of photodiodes. Also, phototransistors, photoconductors, or CCD may be employed. As necessary, microlens for converging the incident light is provided in front of the optical detector element.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG.1 is a perspective view of an embodiment 1 of the invention;

FIG.2 is an illustrative view (No.1) of the production process of the embodiment 1;

FIG.3 is the additional illustrative view (No.2) of the production process of the embodiment 1;

FIG.4 is the additional illustrative view (No.3) of the production process of the embodiment 1;

FIG.5 is a schematic view describing the driving process of the embodiment 1;

FIG.6 is an illustrative view (No.1) of the production process of the embodiment 2;

FIG.7 is another illustrative view of (No.2) of the production process of the embodiment 2;

FIG.8(a) and (b) each is an end view illustrating wirings formed on the torsion bars;

FIG.9 is a perspective view of the embodiment 3;

FIG.10 is a perspective view showing the magnet arrangement;

FIG.11 is a fragmentary views of a torsion bar;

FIG.12 is a fragmentary view of a cantilever;

FIG.13 is another view of a torsion bar;

FIG.14 is an illustrative view No.1 of the production

process of the embodiment 3;

FIG.15 is an illustrative view No.2 of the production process ;

FIG.16 is an illustrative view No.1 of the production process of the embodiment 4;

FIG.17 is an illustrative view No.2 of the production process;

FIG.18 is an illustrative view No.1 of the production process of the embodiment 5;

FIG.19 is an illustrative view No.2 of the production process;

FIG.20 is an illustrative view No.1 of the production process of the embodiment 6;

FIG.21 is an illustrative view No.2 of the production process;

FIG.22 is an illustrative view No.3 of the production process following to FIG.20;

FIG.23 is a perspective view of the embodiment 7;

FIG.24 is an illustrative view No.1 of the production process of a tip of the embodiment 7;

FIG.25 is an illustrative view No.2 of the production process;

FIG.26 is an illustrative view of the production process of a support substrate of the embodiment 7;

FIG.27 is an illustrative view of the assembly process of embodiment 7 ;

FIG.28 is a schematic view describing the driving process of the embodiment 7,

FIG.29 is a diagrammatic view illustrating the resonance property;

FIG.30 is a schematic view of embodiment 8;

FIG.31 is a schematic view describing the driving process of the embodiment 9;

FIG.32 is a plan view of the Related art 1;

FIG.33 is a sectional view of FIG.32;

FIG.34 is a perspective view of the Related art 1;

FIG.35 is a principle diagram for angle detection in the Related art 1;

FIG.36 is a perspective view of the Related art 2;

FIG.37 is a plan view of the Related art 3;

FIG.38 is a sectional view taken along B-B of FIG.37; and

FIG.39 is a sectional view taken along C-C of FIG.37.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

EMBODIMENT 1

FIG.1 shows a summary view of an embodiment of an electromagnetic actuator 100, in which the direction of the optical axis of an optical unit (including a miller, light receiving element, light emitting element, etc) 104 is allowed to swing within a two-dimensional surface, wherein a first and a second driving coils 102 and 103, respectivly, is a one-turn coil of thin film, and connected in series to each other.

The embodiment differs from the Related Art 2 in construction of the driving coil, in arragement of the mermanent magnet, and in the method of actuaing the electromagnetic actuator. But the modified arrangement of the magnet does not cause a variation of the function as the electromagnetic actuator, and rather provides advantages, by utilizing a componet of magetic flux perpendicular to the driving coil, to reduce the nuber of permanent magnets, to simplify the construction and reduce the production cost.

The process of producing the electromagnetic actuator is described referred to FIGS.2 to 4, wherein the thickness is enlarged than the horizontal dimension for clarity, as is the same in FIGS.6 and 7 hereinafter.

The right side figures in both of FIGS.2 and 3 are plan views, and left side figures are sections taken along line A-A'. In step (a), an oxide layers 201 and 202 are formed on the upper and lower surface of a silicone substrate 200. In step (b), the oxide layer 202 is partially removed by photolithography and oxide-layer etching, but leaving a peripheral area 203, an external movable area 204 and an internal movable area 205. In step (c), a thin oxide layer 206 is formed on the areas where the oxide layer has been removed in step (b). In step (d), the oxide layer 206 is partially removed by photolithography and oxide-layer etching, but leaving the areas of a first torsion bar 207 and a second torsion bar 208. In step (e), the areas removed in step (d) is processed by anisotropic etching. In step (f), the oxide layer still remainig is removed. In step (g), by anisotropic etching, a first torsion bar 207, external movable plate 208, second torsion bar 209 and an internal movable plate 210 is formed.

In step (h), aluminum layer 211 is formed on the oxide layer 201 of the upper surface of silicon base 200 by aluminum evaporation. In step (i), the aluminum layer 211 is partially removed by photolithography and aluminum etching to simultaneously form a terminal 212, a wiring 213 on the first torsion bar, a first driving coil 102, a wiring 214 on the second torsion bar, a second driving coil 103, and a miller 215 as an optical element.

As can be seen, the first and second driving coils are connected in series, and connected to terminal 212.

In step (j), an organic protective layer is formed by photolithography so as to surround the first and second driving coils 102 and 103. In step (k), the oxide layers 217, 218 and 202 are removed by oxide layer etching, including one 217 intermediate between the fringe area 203 and external movable plate 208, another oxide layer 218 between the external and internal movable plates 208 and 210, and the remaining oxide layer 202, to form a chip 101.

In step (l), the chip 101 above is placed on and bonded to a separately prepared silicone base 220 having a recessed region 219 in the middle thereof, and in step (m), a pair of permanent magnets 105 and 106 are mounted in diagonal relationship to complete an electromagnetic actuator 100.

To operate the electromagnetic actuator 100, in which the first and second driving coils are connected in

BNSDOCID: <EP___0774681A1_I_>

seires to each other, and both coils are driven by the same current flow, different from the Related art 2. Therefore in the invention, utilizing the differenct between the resonant frequencies of the external movable plate driven by the first driving coil 102 and internal movable plate driven by the second driving coil 103, the external and internal movable plates are separately drive n so as to allow the optical element 104 to swing in the two-dimensional direction.

Suppose that the resonant frequency of the external and internal movable plates are, respectively, 400 and 1600 Hz. As shown in FIG.5 (a), the variable sinusoidal altenating source 51 having 400 Hz(f1) and an output voltage e1, and the variable sinusoidal altenating source 52 having 1600 Hz (f2) and an output voltage e2, are connected in series and further connected to the terminal 212 of the electromagnetic actuator 100.

As a result, the external movable plate 208 is activated by the voltage generated from the a.c. source 51 and is resonated in oscillation at 400 Hz relative to X-axis, while the internal movable plate 210 is also activated by the voltage generated from the a.c. source 52 and is resonated in oscillation at 1600 Hz relative to Y-axis. Thus, as shown in FIG. 5(b), the direction of the optical axis of the optical element 104 oscillates in the two-dimensonal manner as a Lissajous figure traces. When the ratio between the resonant frequencies of external and internal movable plates is set to be an integer, the Lissajous figure turns to move with the time, and thus the fine scanning becomes possible . The swing in the X-direction varies in accordance with changing the voltage of the a.c. source 51, while the swing in the Y-direction varies in accordance with changing the voltage of the a.c. source 52. The mechanical Q of the movable plate of the electromagnetic actuator of this type at a resonant state is high, and the amplitude is substantially decreased, when the source frequency varies even by several Hz. Accordingly, neither the internal movable plate would be activated to oscillate by ac source 51, nor the external movable plate would be activated to oscillate by ac source 52. Also, because of utilizing resonace, and because it is impossible to detect the displacement angle of the movable plate by means of a detecting coil to feedback control the displacement angle, any coil for detection is not needed.

That shown in FIG.5 (a) is an example of being actuated with a votage source having a small internal impendance, while, when actuated by a source having a lage internal impendance, both voltage source is normally connected to the terminal 212.

As discussed above, in the present embodiment, since the coils are connected in series with each one turn, the numbers of terminals, of wirings on each torsion bar, or of turns of each driving coil is reduced, thereby the construction being largely simplified. Since those icl uding the coils, terminals, the wirings of torsion bars, and the miller, are all formed by photolithography and aluminum etching, the number of masks needed for the process is largely reduced to simplify the producti on processes with a lowered costs.

EMBODIMENT 4

As shown in FIGS.16 - 17, the embodiment provides a movable plate having a light weight for preventing damage of the torsion bar in the event of an excessive displacement of the movable plate, such as caused by an external shock.

EMBODIMENT 5

As shown in FIGS.18 and 19, the embodiment provides a combined method by combining the first and second methods, namely providing a stopper and saving the mass of the movable plate.

EMBODIMENT 6

As shown in FIGS.20, 21 and 22, the embodiment provides a stopper and saving the mass of the movable plate, and further through the production process of a higher practical utility.

EMBODIMENT 7

As shown in FIG.23, the embodiment provides an optical element 1108 (including a miller, light receiver, light emitter, etc) which is allowed to oscillate in the two-dimensional manner relative to its optical axis.

EMBODIMENT 8

As shown in FIG.30, the embodiment provides a tip 81, manufactured in the same process as embodiment 7, which is vacuum sealed by pyr ex glass bases 82, 85 and Si spacers 83, 84, thus the response character istics are improved and degradation is prevented.

In this case, the primary coil 86 is formed in outside region.

EMBODIMENT 9

As shown in FIG.31, the embodiment provides the use of a carrier wave for urging from the primary coil to the first and second driving coils.

Claims

1. An electromagnetic actuator comprising:

an external movable plate formed integrally with a semiconductor substrate;
a first torsion bar for swingably support said movable plate with respect to said semiconductor substrate;
an internal movable plate disposed inside said external movable plate;

a second torsion bar rotatably supporting said internal movable plate relative to said external movable plate, and positioned at right angle relative to said first torsion bar; further includeing:
a one-turned first driving coil provided around said external movable plate;
a second driving coil provided around said internal movable plate, and connected in series to said first driving coil;
magnetic field generating means for applying a static magnetic field to said first and second driving coils; and
an optical element formed on said internal movable plate;
a current is caused to flow through said first and second driving coils, and, by using a force produced therefrom, said external and internal movable plates are caused to move, and thus to vary the direction of said optical axis.

2. An electromagnetic actuator comprising:

an external movable plate integrally formed with a semiconductor substrate,
a first torsion bar for swingably support said movable plate with respect to said semiconductor substrate;
an internal movable plate disposed inside said external movable plate;
a second torsion bar rotatably supporting said internal movable plate relative to said external movable plate, and positioned at right angle relative to said first torsion bar; further includeing:
a one-turned, closed-looped first driving coil provided around said external movable plate;
a one-turned, closed-looped second driving coil provided around said internal movable plate, and connected in series to said first driving coil;
magnetic field generating means for applying a static magnetic field to said first and second driving coils; and
an optical element formed on said internal movable plate;
a current is caused to flow through said first and second driving coils, and, by using a force produced therefrom, said external and internal movable plates are caused to move, and thus to vary the direction of said optical axis.

3. A method of manufacturing said electromagnetic actuator according to claim 1 or 2, comprising the steps of:

forming an aluminum layer on a semiconductor substrate by aluminum deposition; and
forming said driving coils from said aluminum layer through phot olithography and aluminum etching.

4. A method of manufacturing said electromagnetic actuator according to claim 1 or 2, comprising the steps of:

forming an aluminum layer on a semiconductor substrate by aluminum deposition; and
forming said driving coils and a miller of said optical element at the same time from said aluminum layer through photolithography and aluminum etching.

5. A method of manufacturing said electromagnetic actuator according to claim 1, comprising the steps of:

forming an aluminum layer on a semiconductor substrate by aluminum deposition; and
forming said driving coils and wiring on said torsion bar at the same time from said aluminum layer through photolithography and aluminum etching.

6. An electromagnetic actuator comprising:

movable plates formed integrally with a semiconductor substrate;
a torsion bar for swingably support said movable plate with resp ect to said semiconductor substrate;
driving coils provided around said movable plate;
magnetic field generating means for applying a static magnetic field to said driving coils;
an optical element formed on said movable plate;
a current is caused to flow through said first and second driving coils, and, by using a force produced therefrom, said movable plates are caused to move, and thus to vary the direction of said optical axis , and
a stopper disposed in facing at least one surface of said movable plate for preventing an excessive displacement of said movable plate in the event of receiving a physical shock.

7. An electromagnetic actuator comprising:

an external movable plate formed integrally with a semiconductor substrate;
a first torsion bar for swingably support said movable plate with respect to said semiconductor substrate;
an internal movable plate disposed inside said external movable plate;
a second torsion bar rotatably supporting said internal movable plate relative to said external movable plate, and positioned at right angle relative to said first torsion bar; further includeing:
a one-turned first driving coil provided around

BNSDOCID: <EP___0774681A1_I_>

said external movable plate;

a second driving coil provided around said internal movable plate, and connected in series to said first driving coil;

magnetic field generating means for applying a static magnetic field to said first and second driving coils;

an optical element formed on said internal movable plate;

a current is caused to flow through said first and second driving coils, and, by using a force produced therefrom, said external and internal movable plates are caused to move, and thus to vary the direction of said optical axis; and

a stopper disposed in facing at least one surface of said movable plates for preventing an excessive displacement of said movable plat es in the event of receiving a physical shock.

8. An electromagnetic actuator according to claim 6 or 7, wherein said stopper is a beam member, provided away from the range of said movable plate being rocked, and extending in parallel with said torsion bar.

9. An electromagnetic actuator comprising:

movable plates formed integrally with a semiconductor substrate;

a torsion bar for swingably support said movable plate with resp ect to said semiconductor substrate;

driving coils provided around said movable plate;

magnetic field generating means for applying a static magnetic field to said driving coils;

an optical element formed on said movable plate;

a current is caused to flow through said first and second driving coils, and, by using a force produced therefrom, said movable plates are caused to move, and thus to vary the direction of said optical axis , and

said movable plates is formed as a thin film from said semiconductor substrate.

10. An electromagnetic actuator comprising:

an external movable plate formed integrally with a semiconductor substrate;

a first torsion bar for swingably support said movable plate with respect to said semiconductor substrate;

an internal movable plate disposed inside said external movable plate;

a second torsion bar rotatably supporting said internal movable plate relative to said external movable plate, and positioned at right angle relative to said first torsion bar; further includeing:

a one-turned first driving coil provided around said external movable plate;

a second driving coil provided around said internal movable plate, and connected in series to said first driving coil;

magnetic field generating means for applying a static magnetic field to said first and second driving coils;

an optical element formed on said internal movable plate;

a current is caused to flow through said first and second driving coils, and, by using a force produced therefrom, said external and internal movable plates are caused to move, and thus to vary the direction of said optical axis; and

said external and internal movable plates is formed as a thin film from said semiconductor substrate.

11. An electromagnetic actuator according to claim 6, 7 or 8, wherein said movable plates are of thin film formed from said semiconductor sub strate.

12. An electromagnetic actuator comprising:

movable plates formed integrally with a semiconductor substrate;

a torsion bar for swingably support said movable plate with resp ect to said semiconductor substrate;

driving coils provided around said movable plate;

magnetic field generating means for applying a static magnetic field to said driving coils;

an optical element formed on said movable plate;

a primary coil electromagnetically connected to said driving coils;

a current is caused to flow through said primary coil in said driving coils, and, by using a force produced therefrom, said movable plates are caused to move, and thus to vary the direction of said optical axis.

13. An electromagnetic actuator comprising:

an external movable plate formed integrally with a semiconductor substrate;

a first torsion bar for swingably support said movable plate with respect to said semiconductor substrate;

an internal movable plate disposed inside said external movable plate;

a second torsion bar rotatably supporting said internal movable plate relative to said external movable plate, and positioned at right angle relative to said first torsion bar; further including:

a first driving coil formed as a closed-loop provided around said external movable plate;

BNSDOCID: <EP___0774681A1_I_>

a second driving coil formed as a closed-loop provided around said internal movable plate;

magnetic field generating means for applying a static magnetic field to said first and second driving coils;

an optical element formed on said internal movable plate;

a primary coil electromagnetically coupled to said first and second driving coils; and

a current is caused to flow through said primary coil in said driving coils, and, by utilizing a force produced therefrom, said movable plates are caused to move, and thus to vary the direction of said optical axis.

14. An electromagnetic actuator comprising:

movable plates integrally formed with a semiconductor substrate;

a torsion bar for swingably support said movable plate with respect to said semiconductor substrate;

driving coils provided around said movable plate for forming a closed loop via a diode;

magnetic field generating means for applying a static magnetic field to said driving coils;

an optical element formed on said movable plate;

a primary coil electromagnetically coupled to said driving coils;

a demodulation current is caused to flow through said primary coil in said driving coils, and, by using a force produced therefrom, said movable plates are caused to move, and thus to vary the direction of said optical axis.

15. An electromagnetic actuator comprising:

an external movable plate formed integrally with a semiconductor substrate;

a first torsion bar for swingably support said movable plate with respect to said semiconductor substrate;

an internal movable plate disposed inside said external movable plate;

a second torsion bar rotatably supporting said internal movable plate relative to said external movable plate, and positioned at right angle relative to said first torsion bar; further includeing:

a first driving coil provided around said external movable plate , and forming a closed loop through a diode;

a second driving coil provided around said internal movable plate, and forming a closed loop through a diode;

magnetic field generating means for applying a static magnetic field to said first and second driving coils;

an optical element formed on said movable plate;

a primary coil electromagnetically coupled to said driving coils; and

a demodulation current is caused to flow through said primary coil in said driving coils, and, by using a force produced therefrom, said movable plates are caused to move, and thus to vary the direction of said optical axis.

16. An electromagnetic actuator according to claim 12 to 15, wherein the area including said movable plates, torsion bars and driving coils is arranged in a vacuum or gas encapsulated region, while said first driving coil is disposed away from said region.

17. An electromagnetic actuator comprising:

an external movable plate formed integrally with a semiconductor substrate;

a first torsion bar for swingably support said movable plate with respect to said semiconductor substrate;

an internal movable plate disposed inside said external movable plate;

a second torsion bar rotatably supporting said internal movable plate relative to said external movable plate, and positioned at right angle relative to said first torsion bar; further includeing:

a first driving coil forming a closed loop around said external movable plate;

a second driving coil forming a closed loop around said internal movable plate;

magnetic field generating means for applying a static magnetic field to said first and second driving coils;

an optical element formed on said internal movable plate;

a primary coil electromagnetically coupled to said second driving coil; and

a current is caused to flow from the exterior to flow in said second driving coil through said primary coil, and, by using a force produced therefrom, said movable plates are caused to move, and thus to vary the direction of said optical axis.

18. An electromagnetic actuator comprising:

an external movable plate formed integrally with a semiconductor substrate;

a first torsion bar for swingably support said movable plate with respect to said semiconductor substrate;

an internal movable plate disposed inside said external movable plate;

a second torsion bar rotatably supporting said internal movable plate relative to said external movable plate, and positioned at right angle relative to said first torsion bar; further includeing:

BNSDOCID: <EP___0774681A1_I_>

a first driving coil forming a closed loop around said external movable plate;

a second driving coil forming, via a diode, a closed loop around said internal movable plate;

magnetic field generating means for applying a static magnetic field to said first and second driving coils;

an optical element formed on said movable plate;

a primary coil electromagnetically coupled to said second driving coil; and

a current is caused to flow from the exterior to urge said second driving coil by said primary coil, a demodulation current is caused to flow through said second driving coil, and, by using a force produced therefrom, said movable plates are caused to move, and thus to vary the direction of said optical axis.

19. A method of manufacturing said electromagnetic actuator according to claim 12 to 18, comprising the steps of:

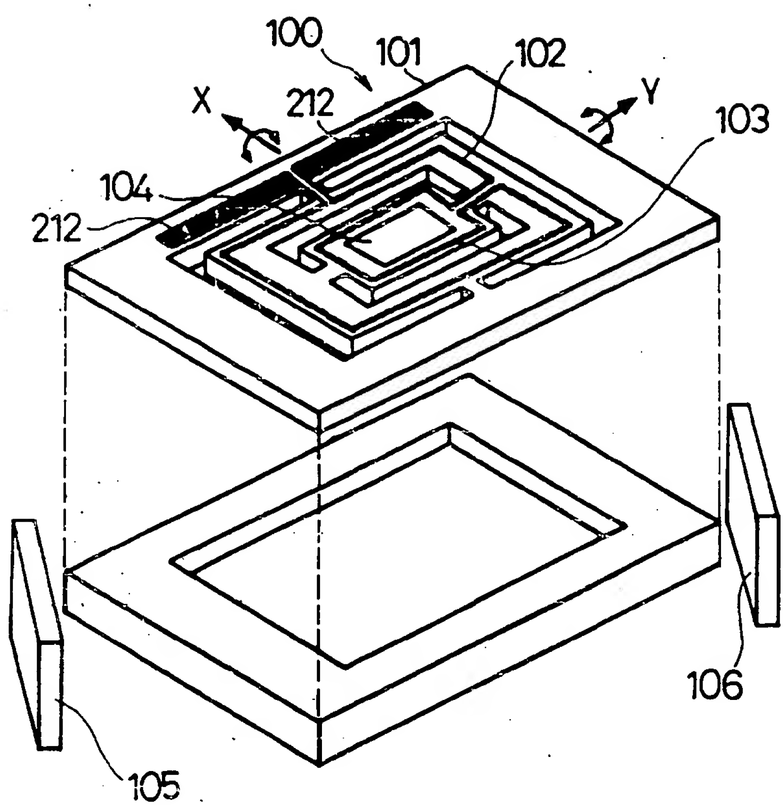
depositing an aluminum layer on said semiconductor substrate by vacuum evaporation, and forming said driving coils from said aluminum layer through photolithography and aluminum etching.

20. A method of manufacturing said electromagnetic actuator according to claim 12 to 18, comprising the steps of:

depositing an aluminum layer on said semiconductor substrate by vacuum evaporation, and forming said driving coils, optical element and miller are simultaneously from said alumimum layer through photolithography and aluminum etching.

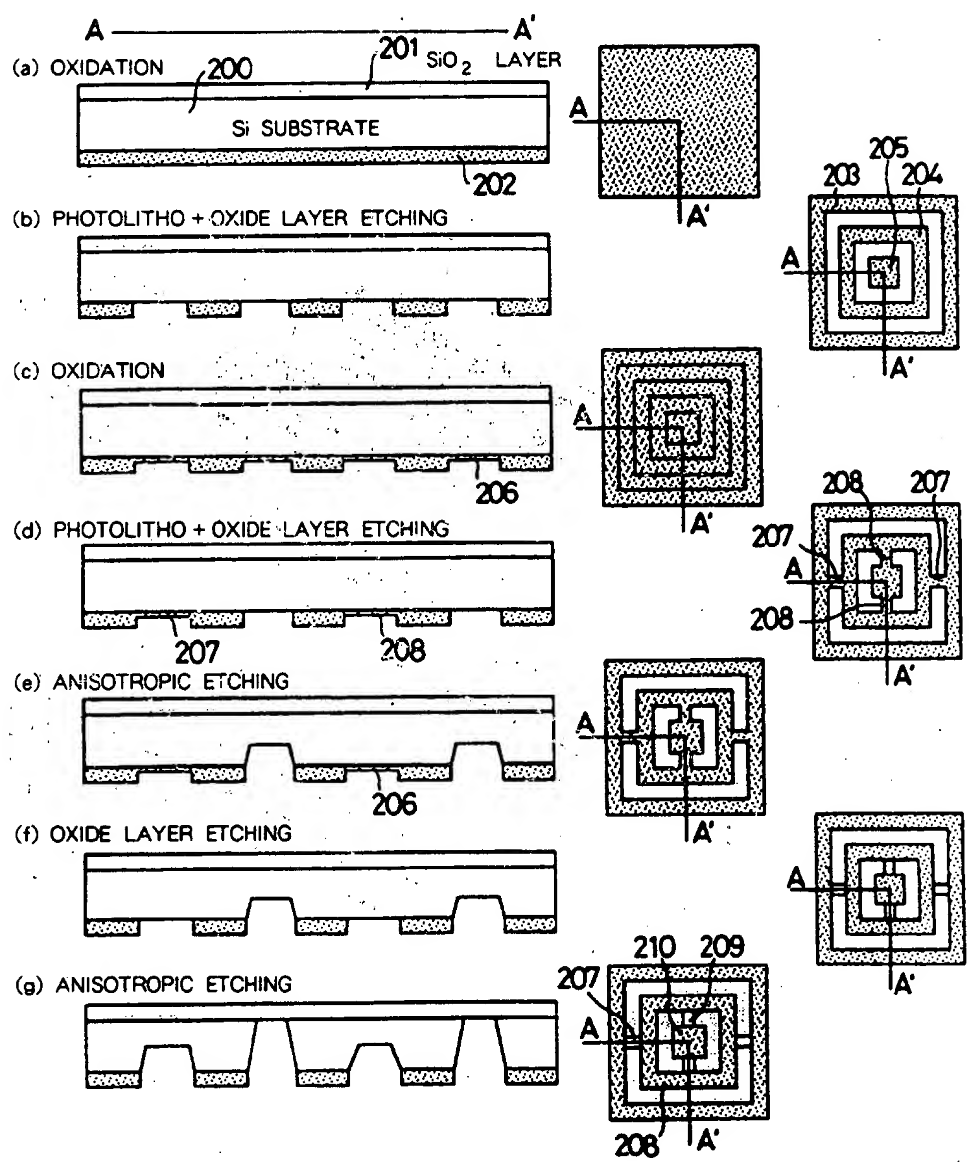
BNSDOCID: <EP___0774681A1_I_>

FIG. 1



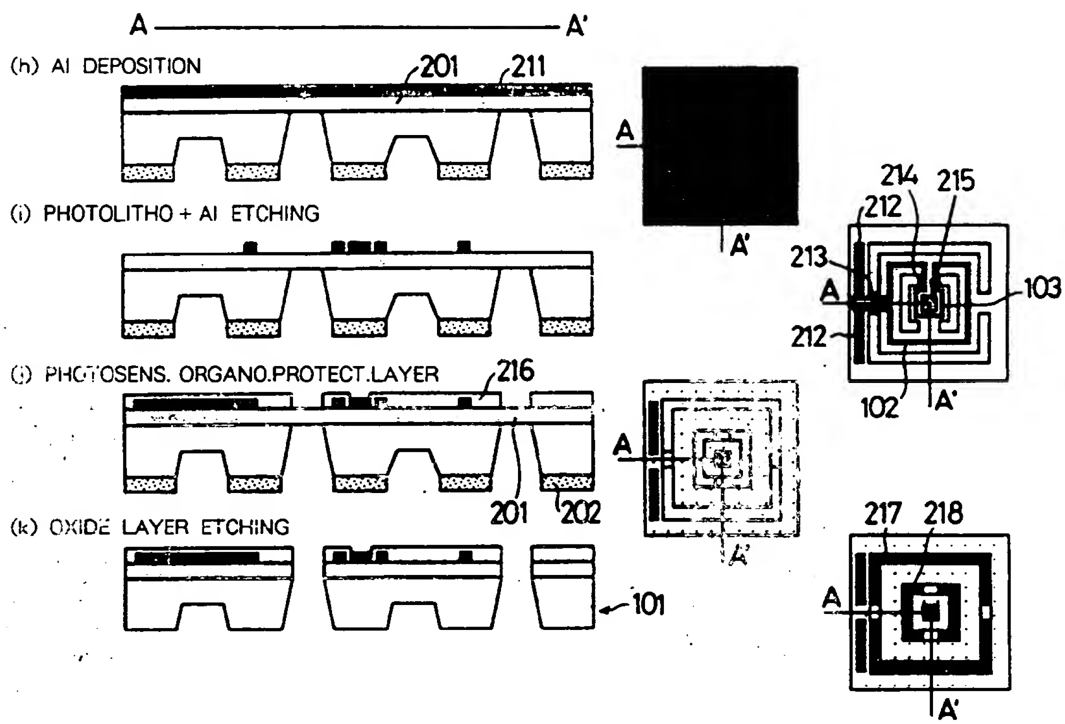
BNSDOCID: <EP___0774681A1_I_>

FIG.2



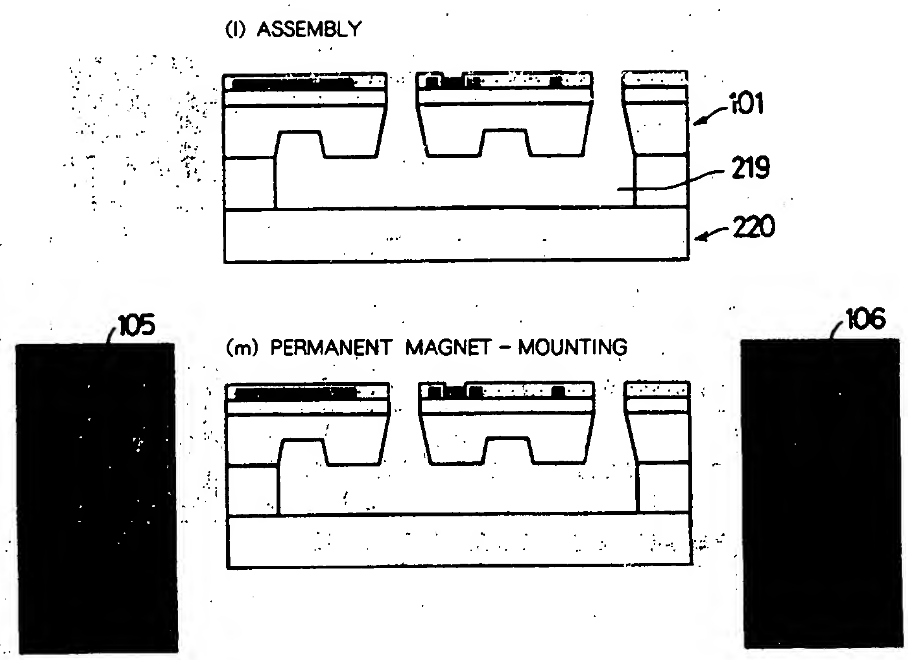
BNSDOCID: <EP___0774681A1_I_>

FIG.3



BNSDOCID: <EP___0774681A1_I_>

FIG.4



BNSDOCID: <EP___0774681A1_I_>

FIG.5 (a)

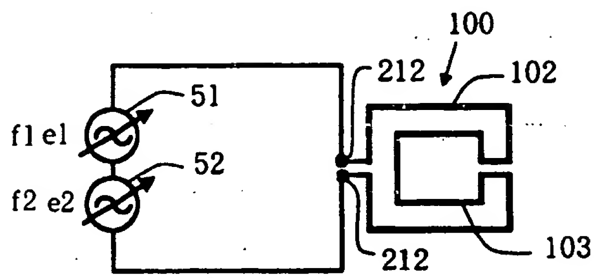
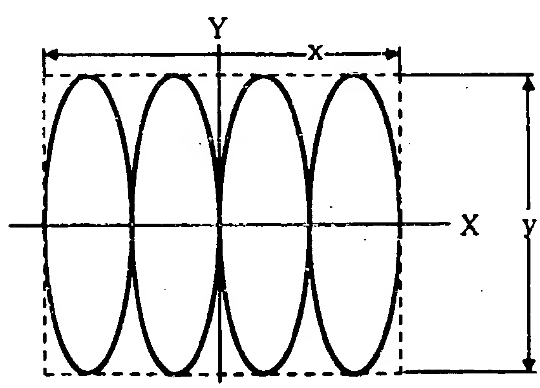
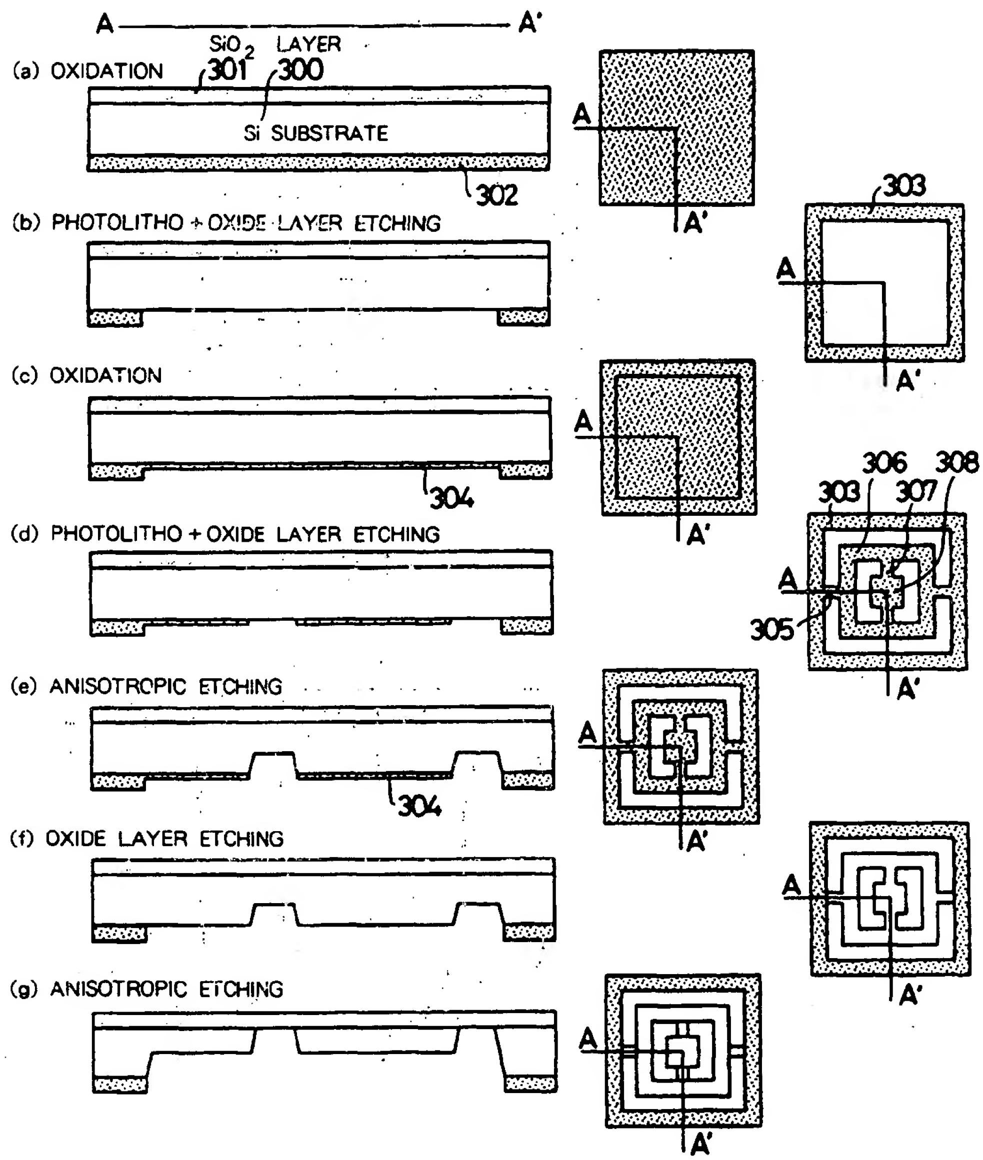


FIG.5 (b)



BNSDOCID: <EP___0774681A1_I_>

FIG.6



BNSDOCID: <EP___0774681A1_I_>

FIG.7

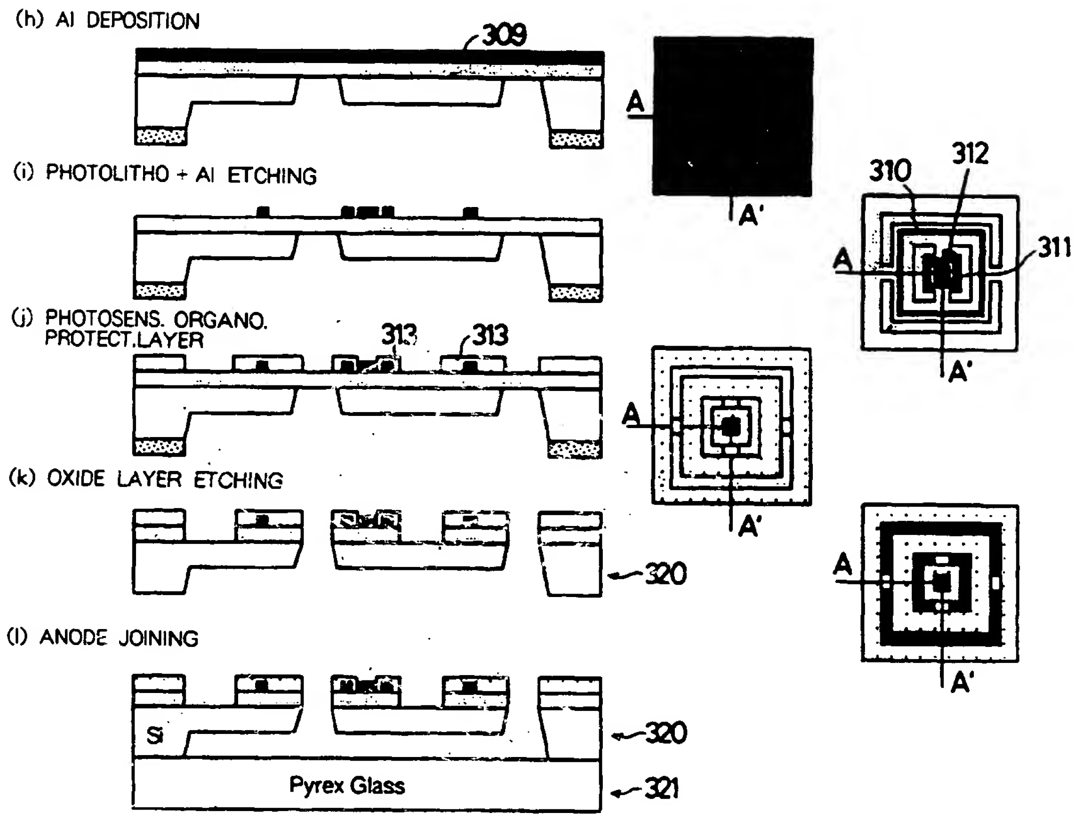


FIG.8 (a)

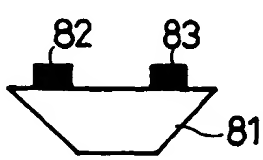
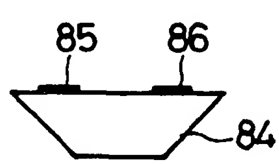
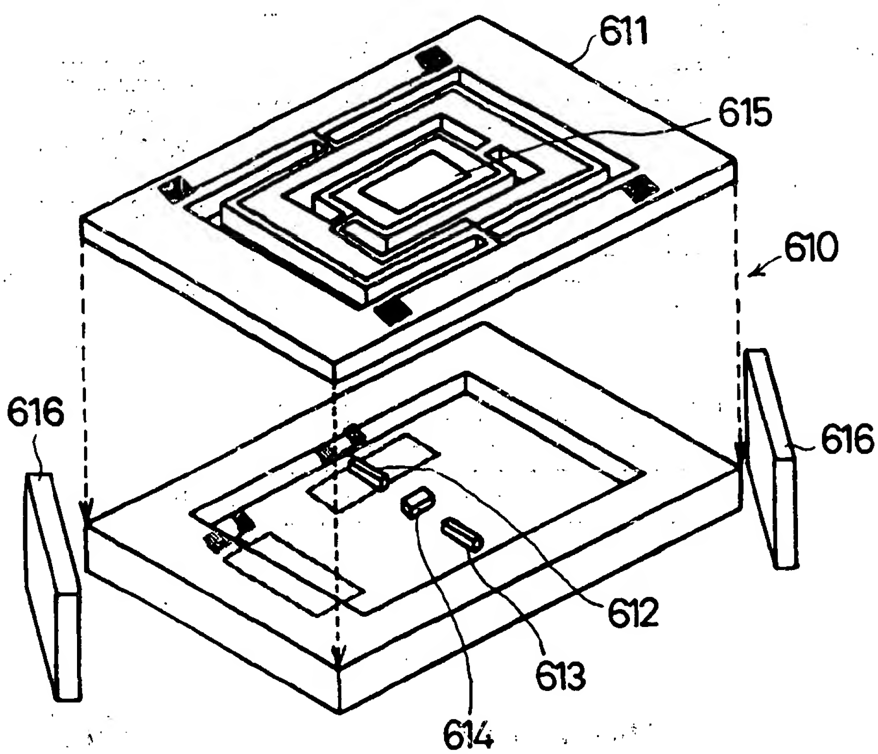


FIG.8 (b)



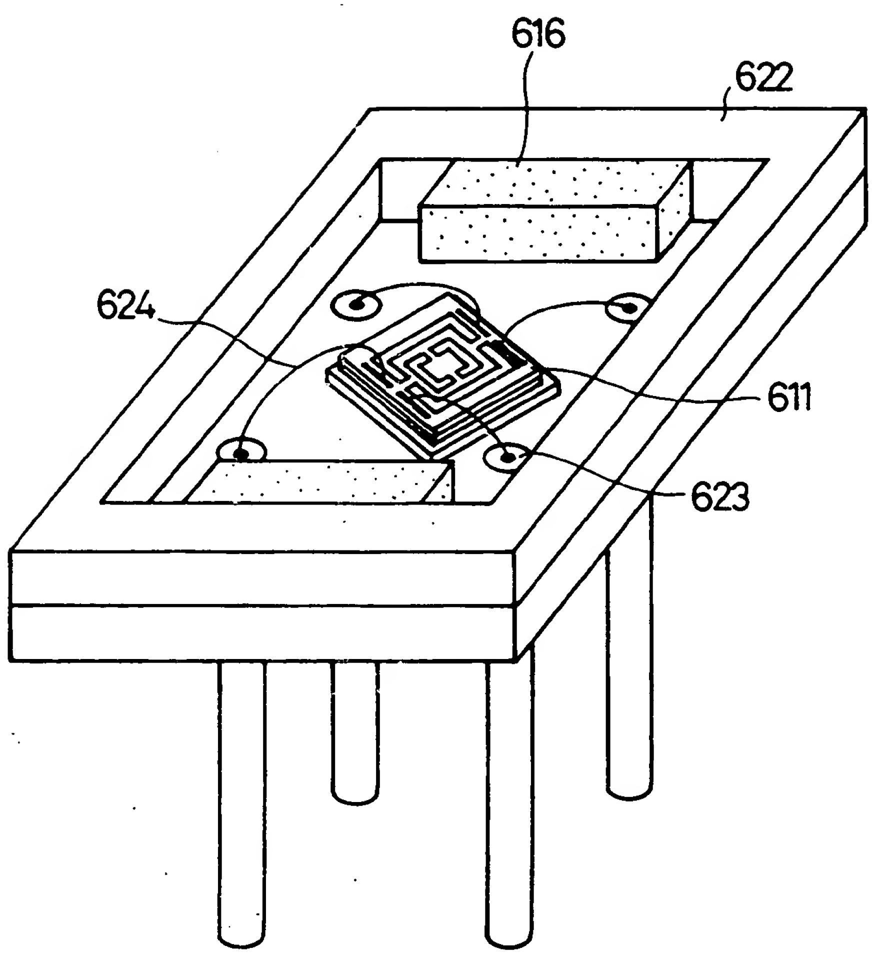
BNSDOCID: <EP___0774681A1_I_>

FIG.9



BNSDOCID: <EP___0774681A1_I_>

FIG. 10



BNSDOCID: <EP___0774681A1_I_>

FIG.11 (a)

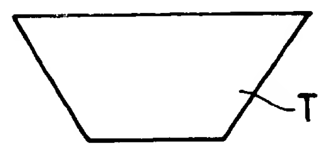


FIG.11 (b)

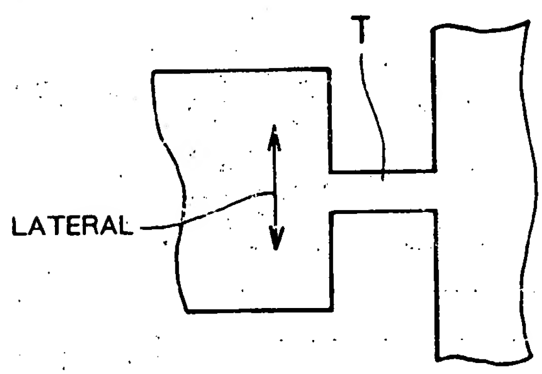
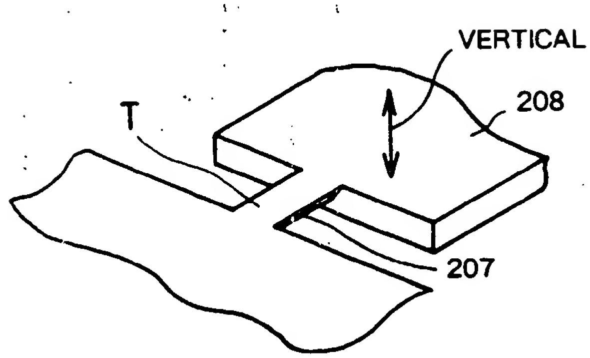


FIG.11 (c)



BNSDOCID: <EP___0774681A1_I_>

FIG.12

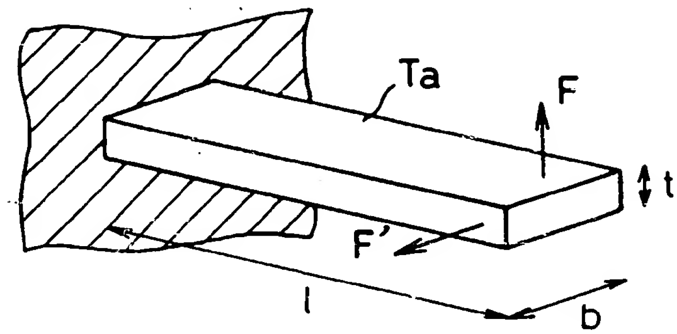
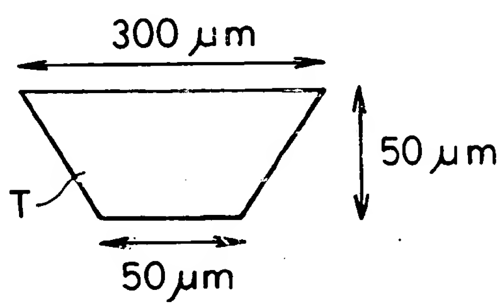
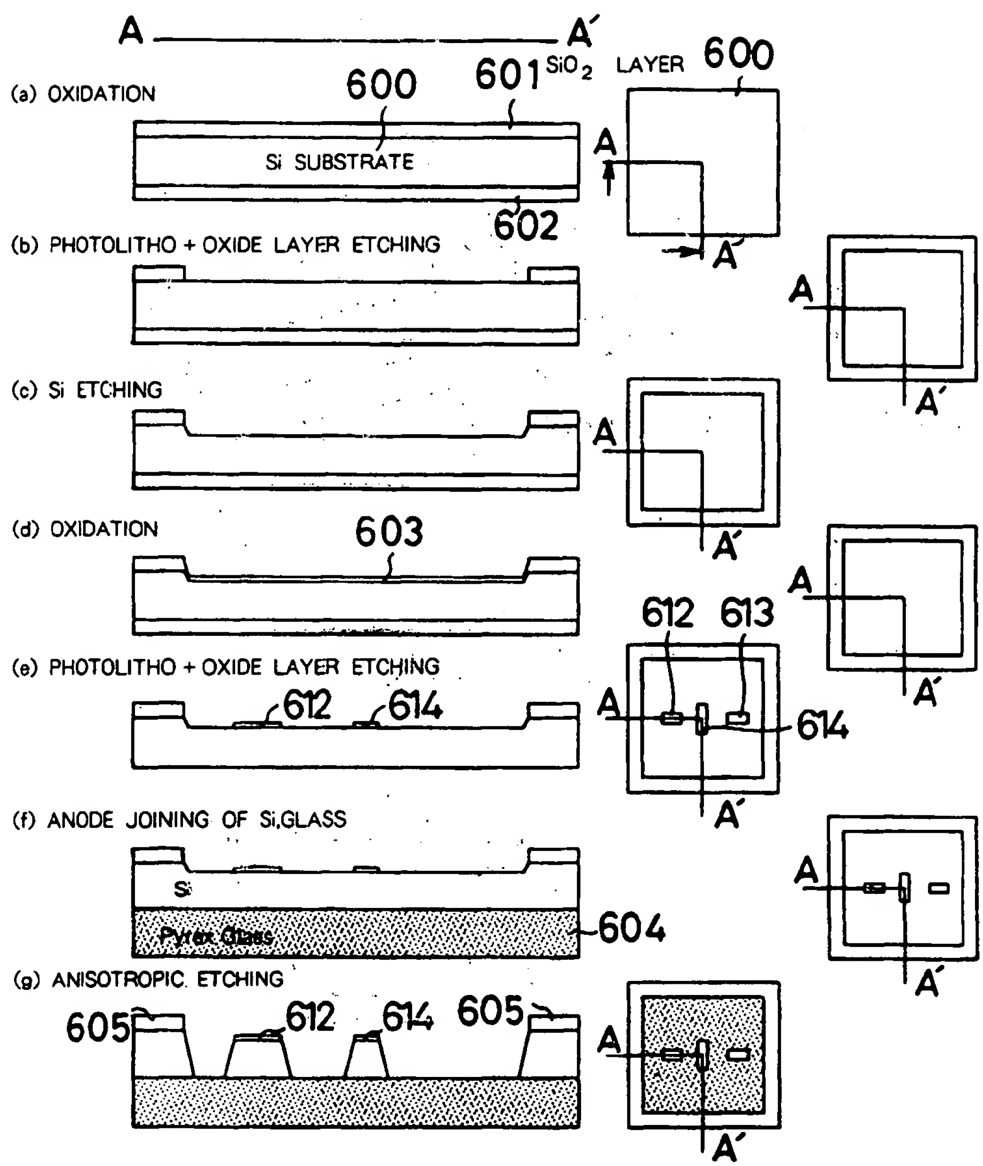


FIG.13



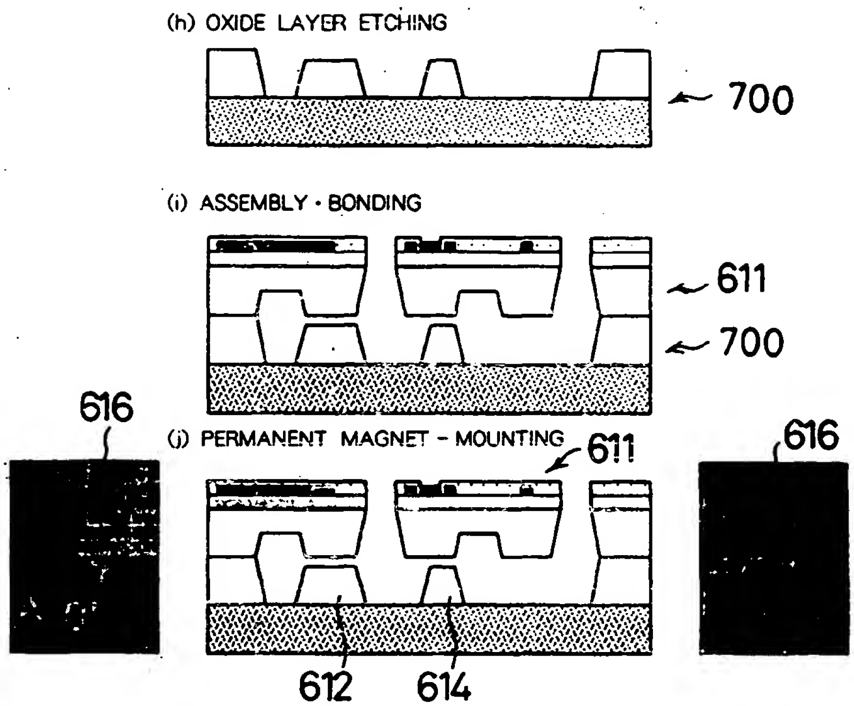
BNSDOCID: <EP___0774681A1_I_>

FIG. 14



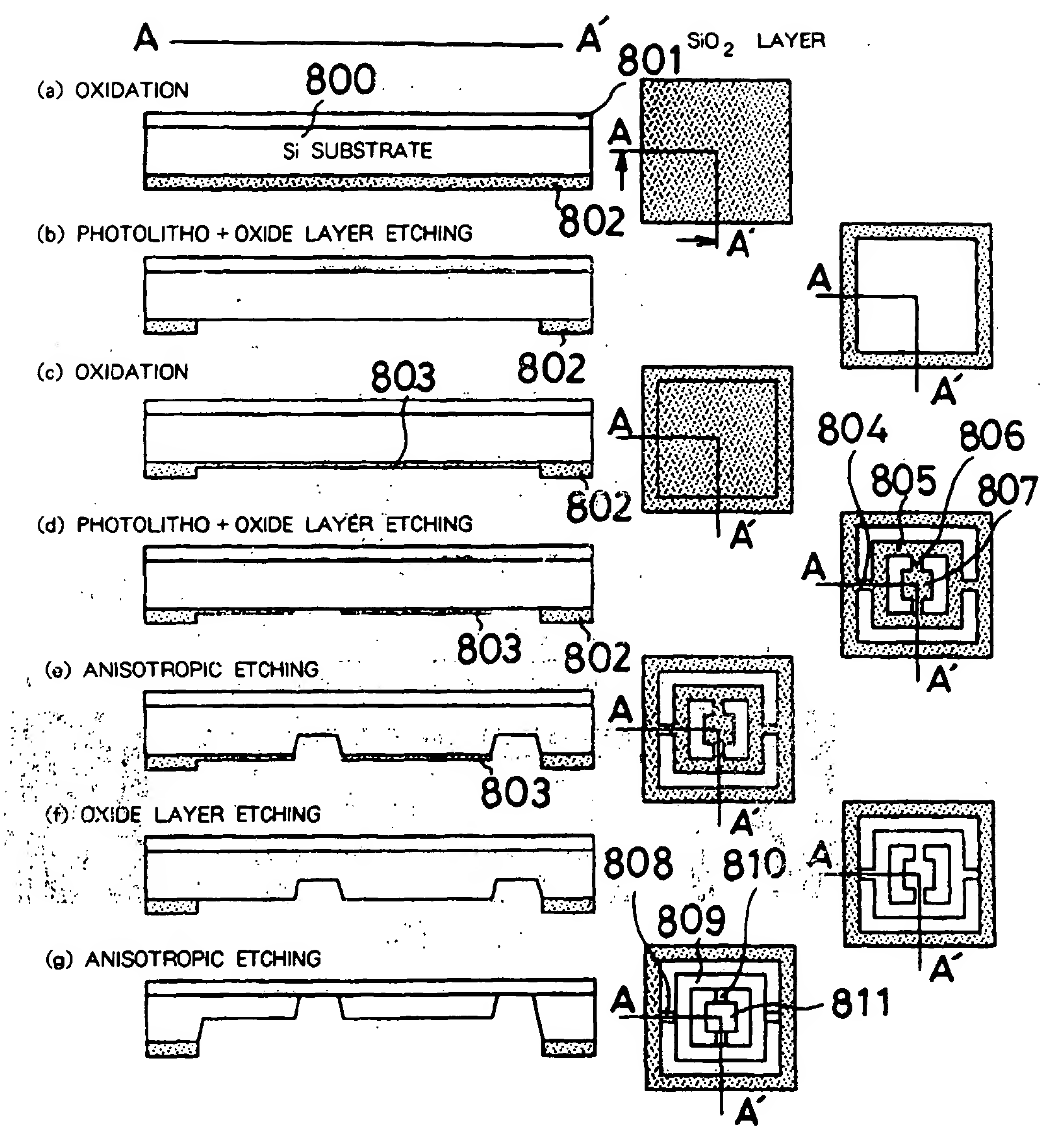
BNSDOCID: <EP___0774681A1_I_>

FIG. 15



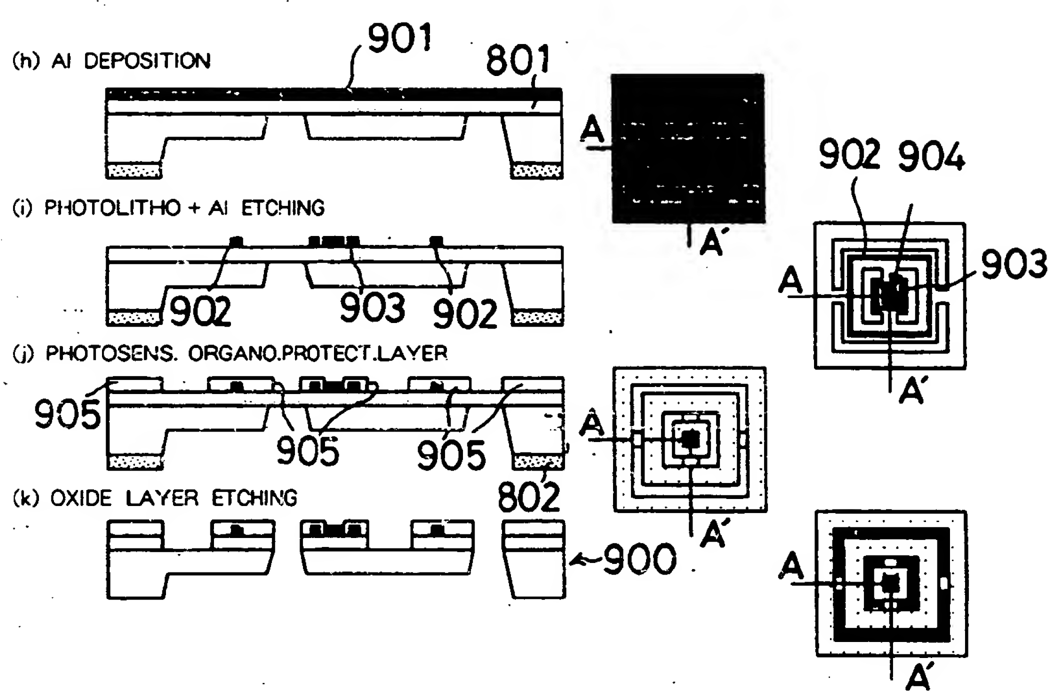
BNSDOCID: <EP___0774681A1_I_>

FIG. 16



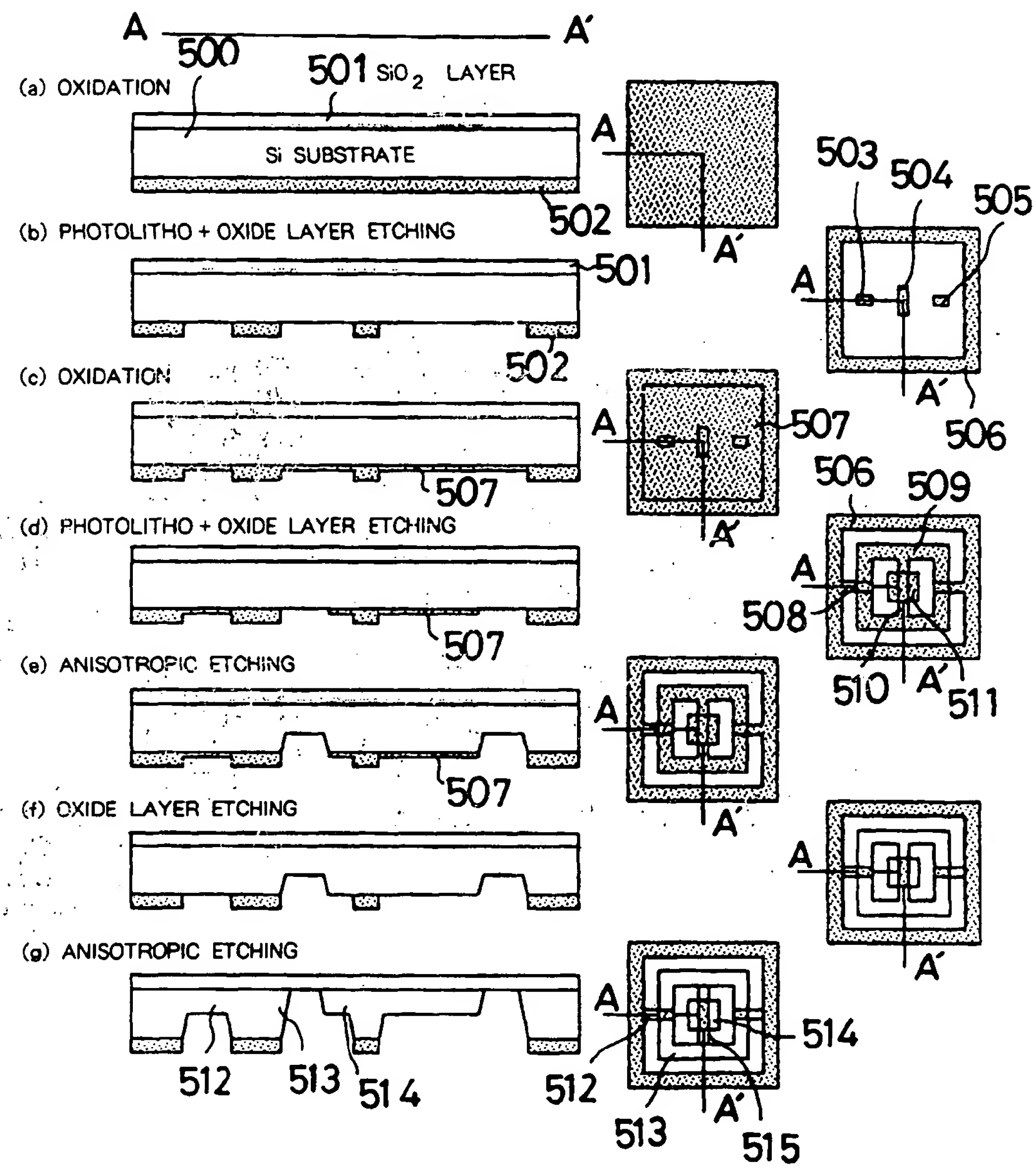
BNSDOCID: <EP___0774681A1_I_>

FIG. 17



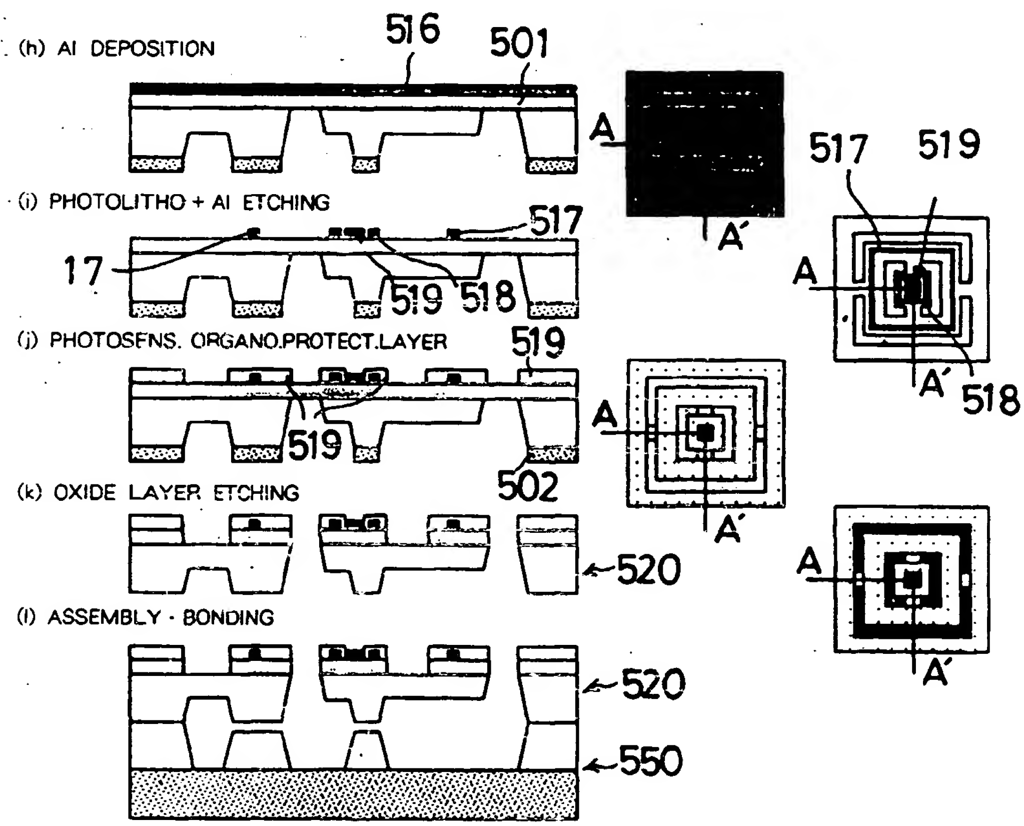
BNSDOCID: <EP___0774681A1_I_>

FIG.18



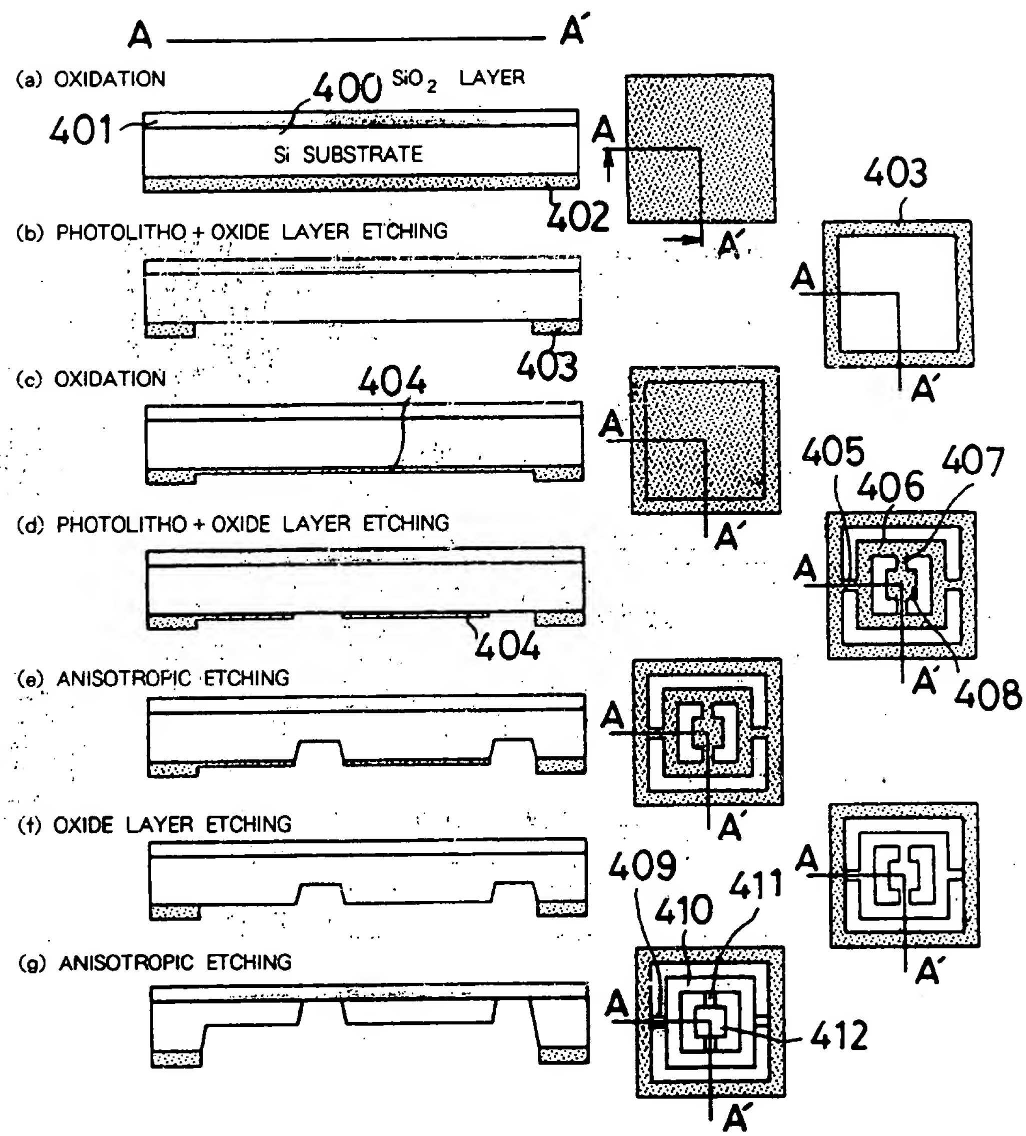
BNSDOCID: <EP___0774681A1_I_>

FIG.19



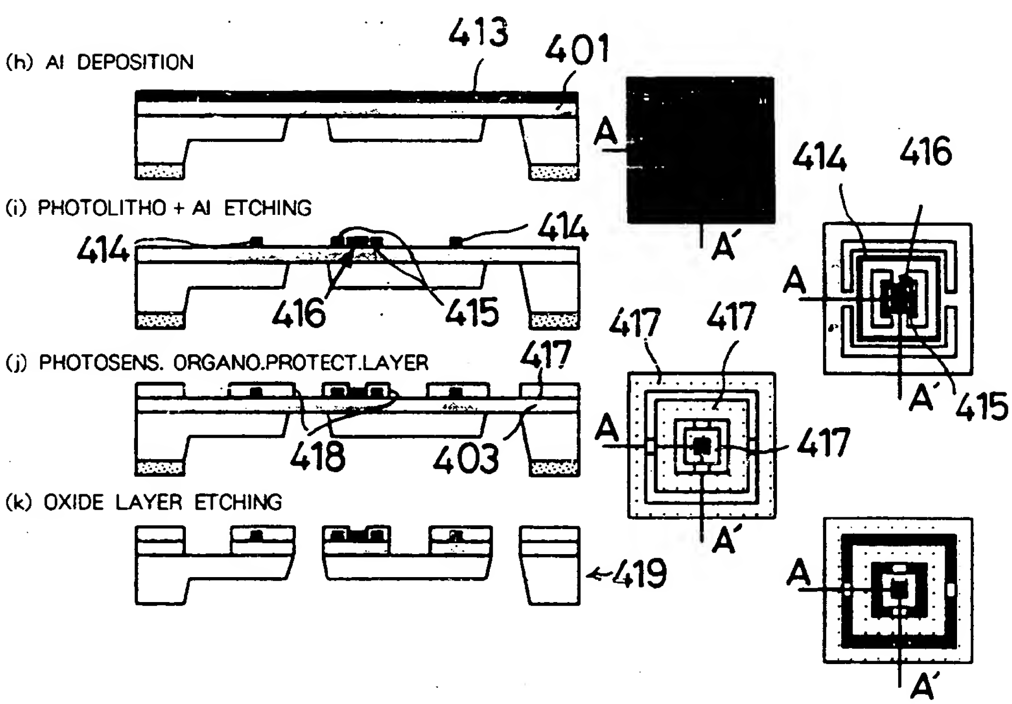
BNSDOCID: <EP___0774681A1_I_>

FIG.20



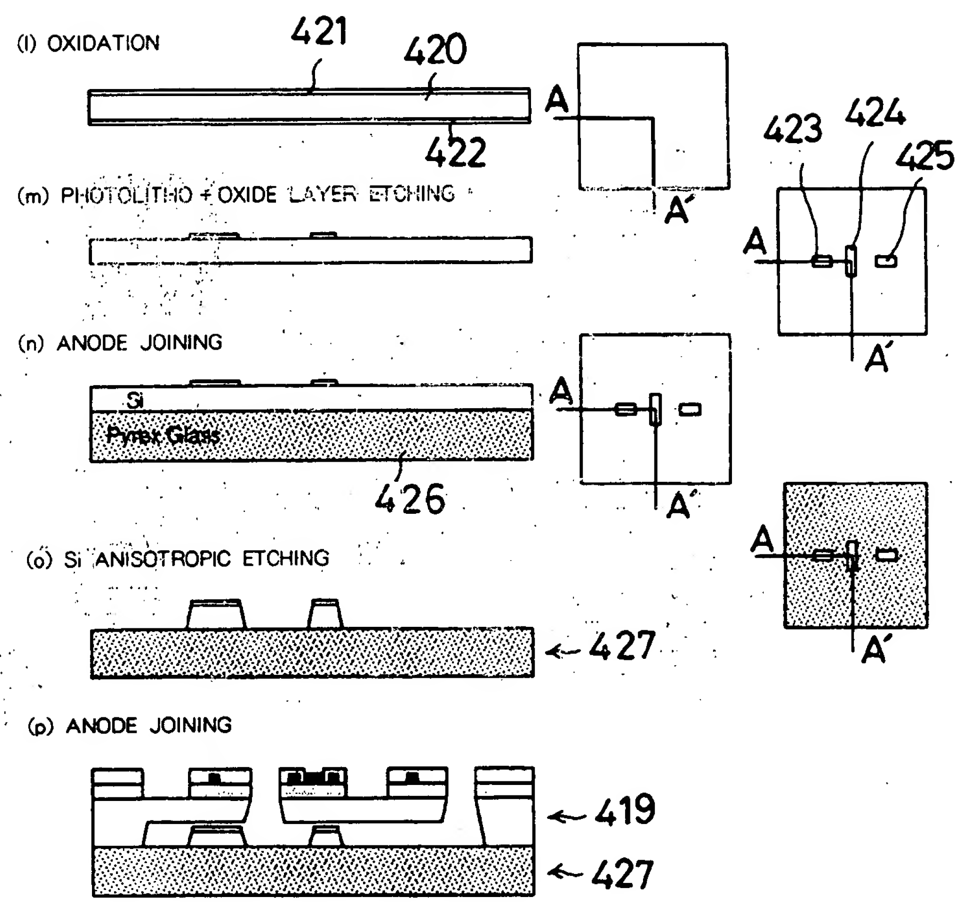
BNSDOCID: <EP___0774681A1_I_>

FIG.21



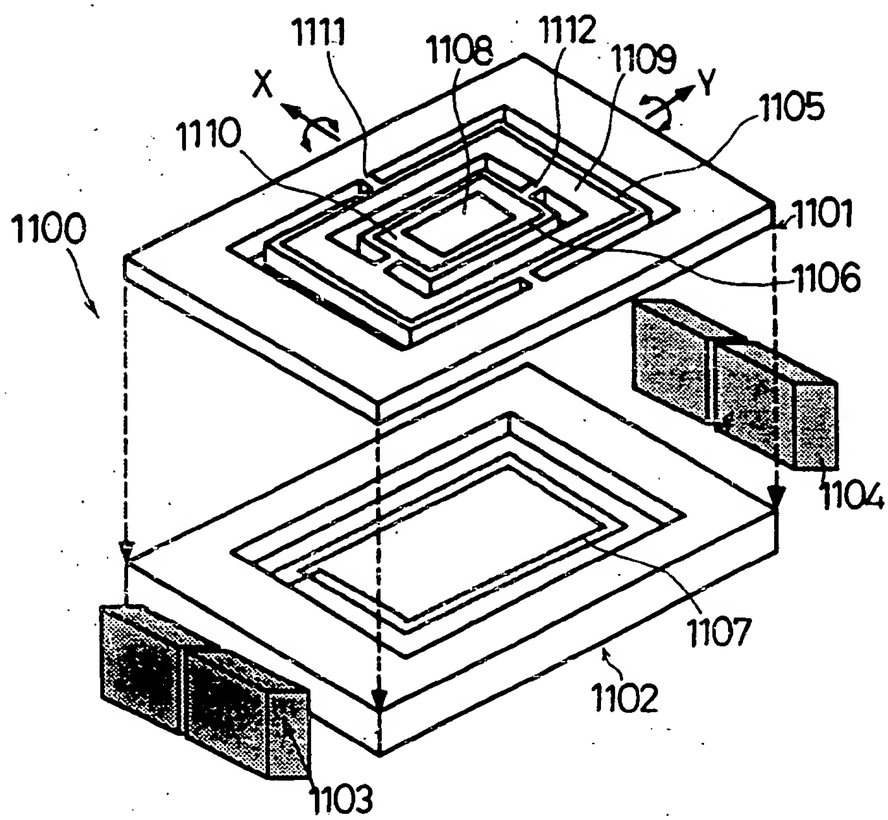
BNSDOCID: <EP___0774681A1_I_>

FIG.22



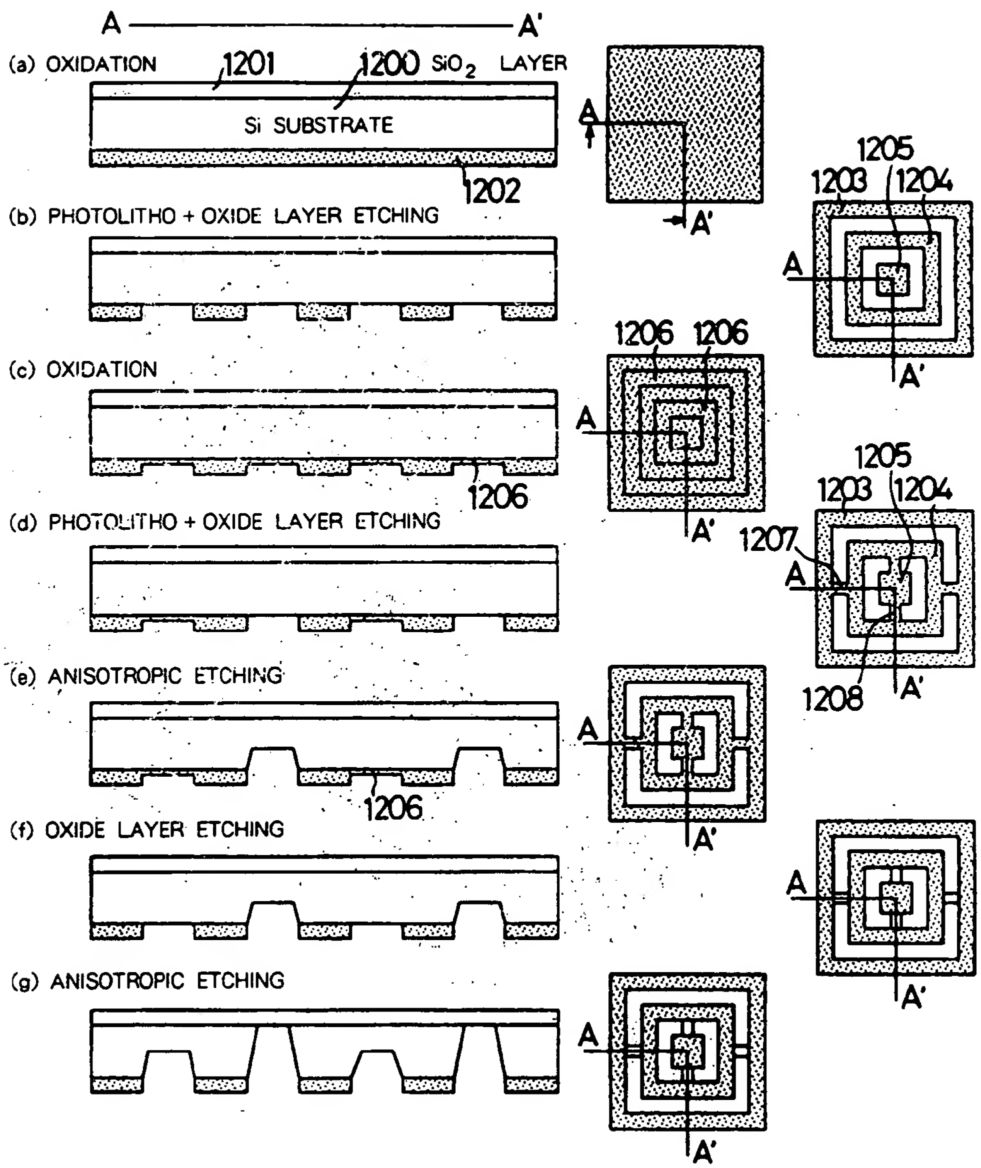
BNSDOCID: <EP___0774681A1_I_>

FIG.23



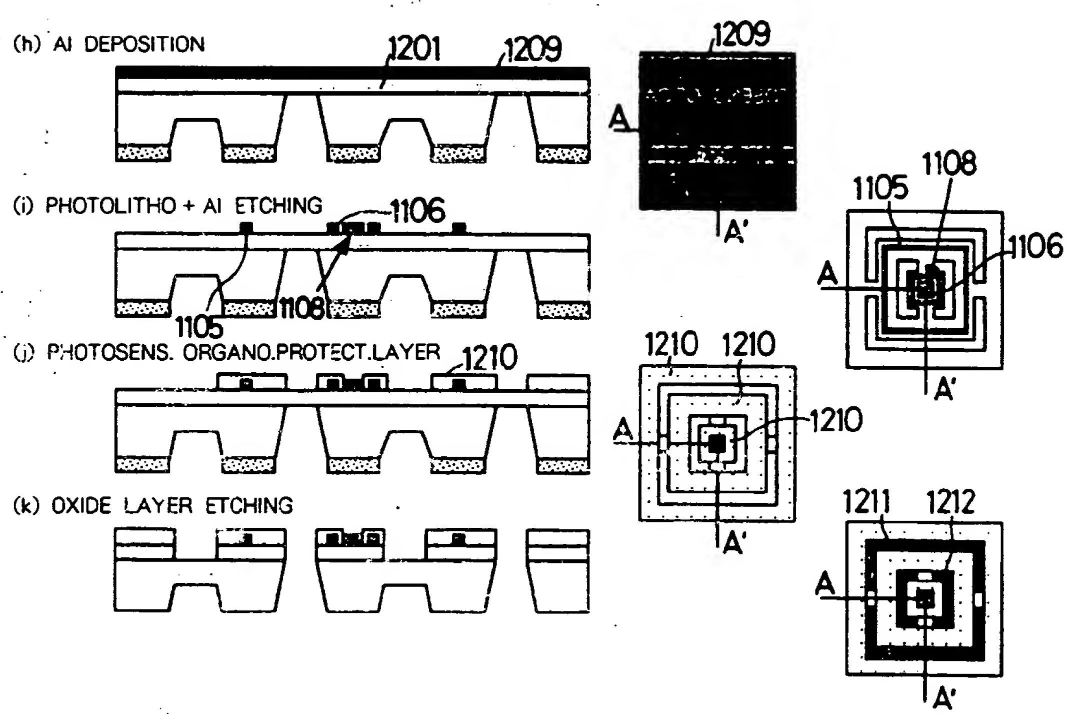
BNSDOCID: <EP___0774681A1_I_>

FIG.24



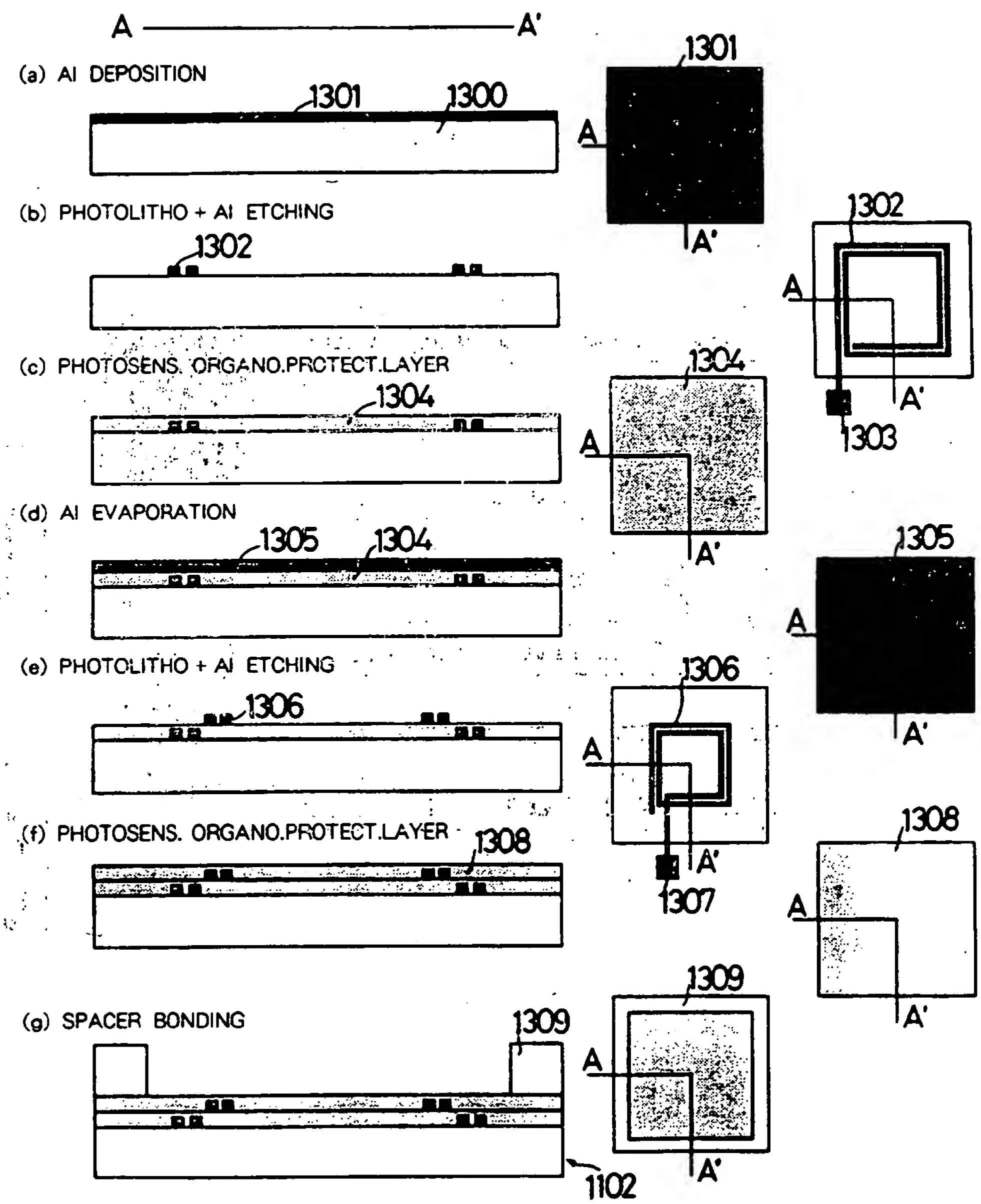
BNSDOCID: <EP___0774681A1_I_>

FIG.25



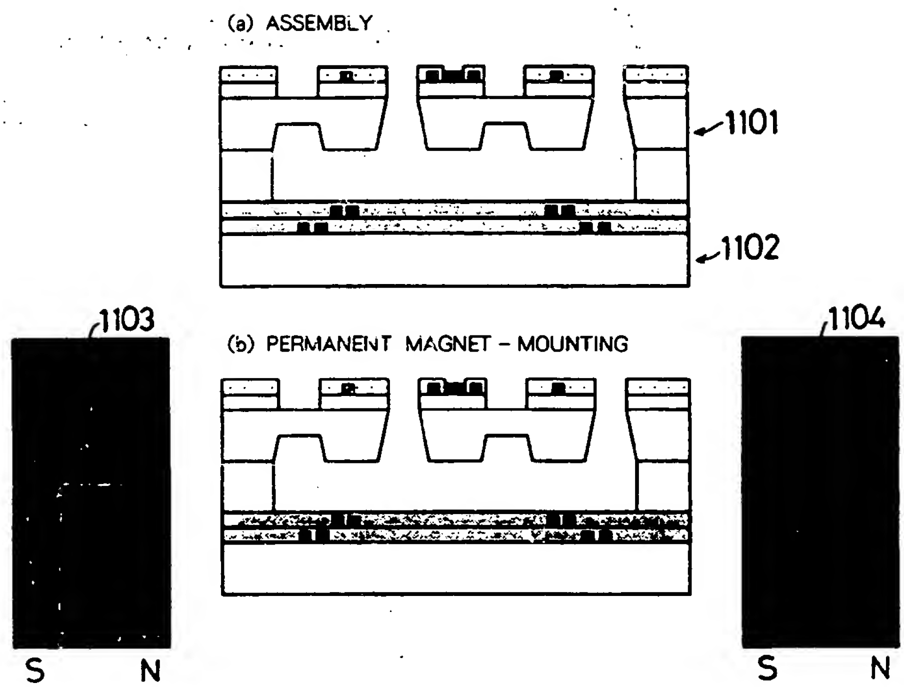
BNSDOCID: <EP___0774681A1_I_>

FIG.26



BNSDOCID: <EP___0774681A1_I_>

FIG.27



BNSDOCID: <EP___0774681A1_I_>

FIG.28 (a)

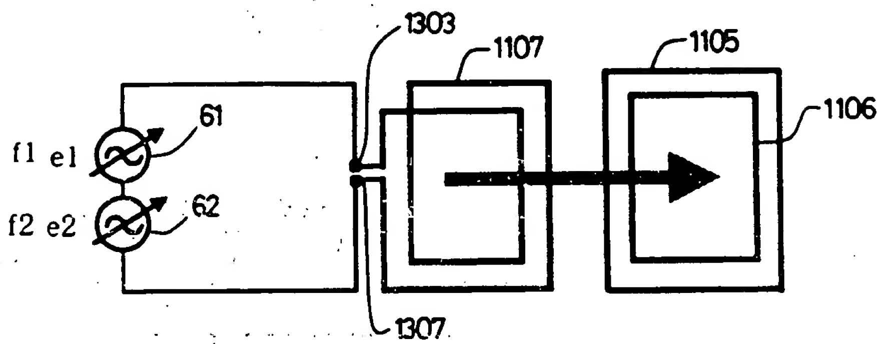
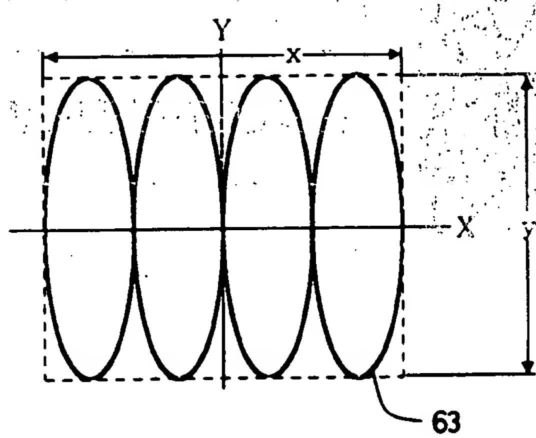


FIG.28 (b)



BNSDOCID: <EP___0774681A1_I_>

FIG.29 (a)

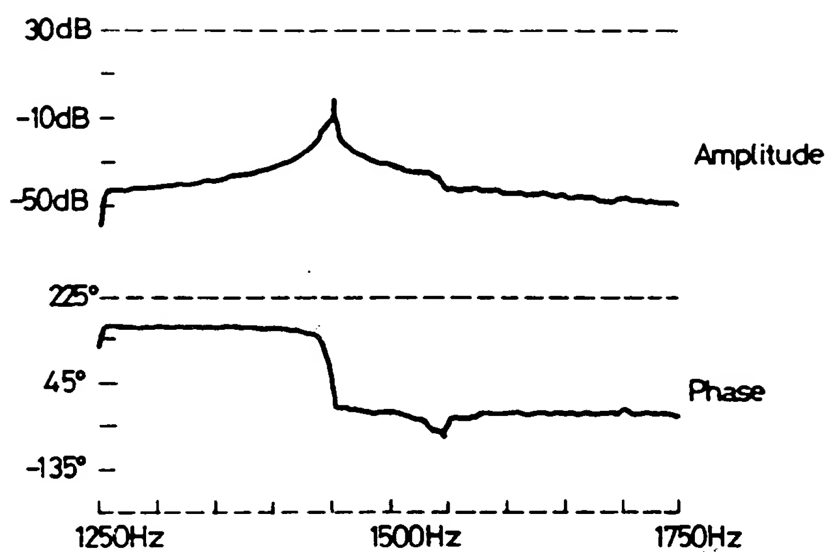
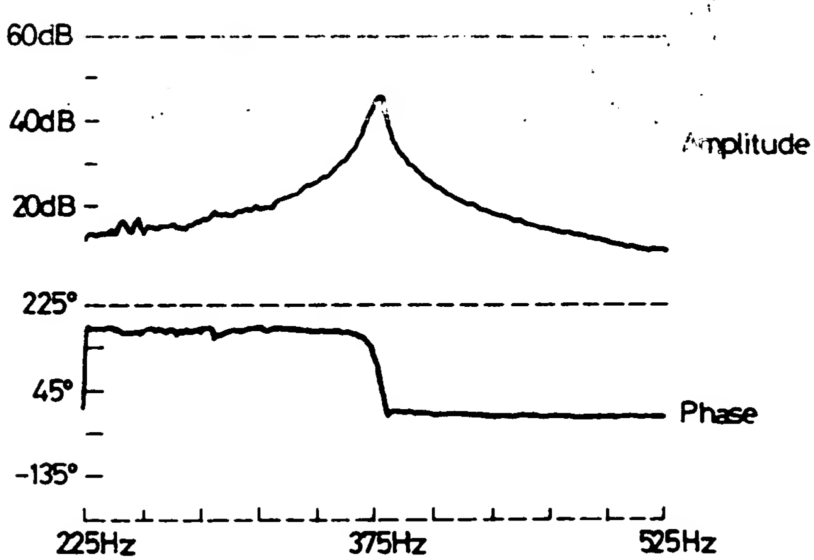
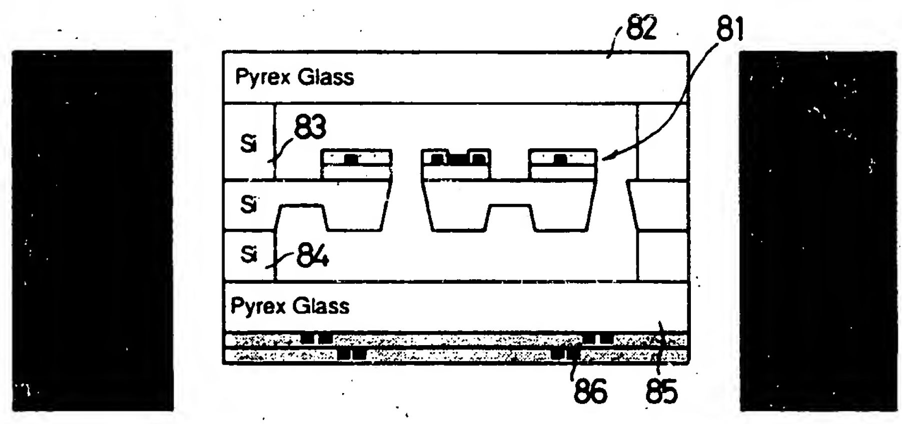


FIG.29 (b)



BNSDOCID: <EP___0774681A1_I_>

FIG.30



BNSDOCID: <EP___0774681A1_I_>

FIG.31 (a)

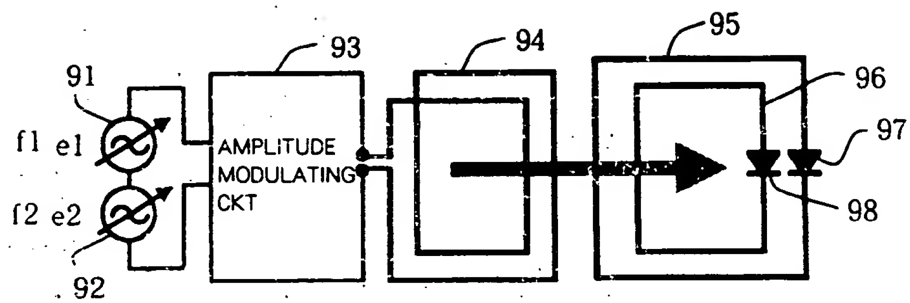
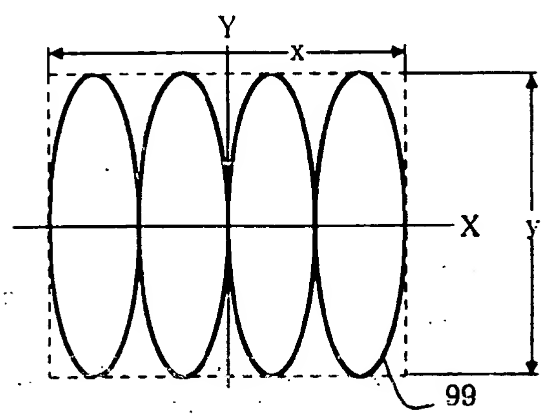


FIG.31 (b)



BNSDOCID: <EP___0774681A1_I_>

FIG.32

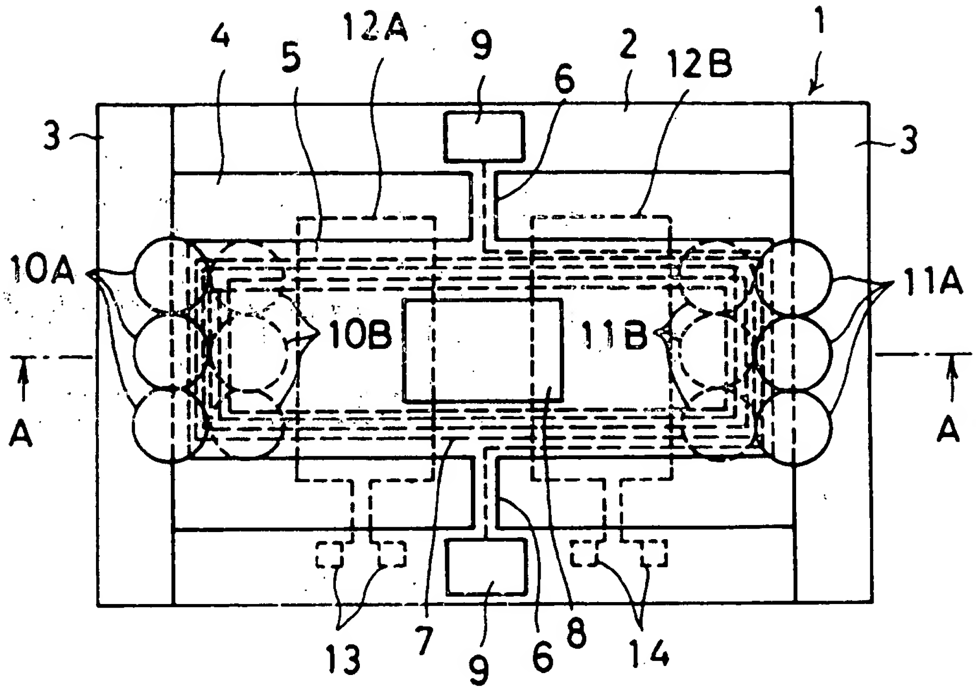
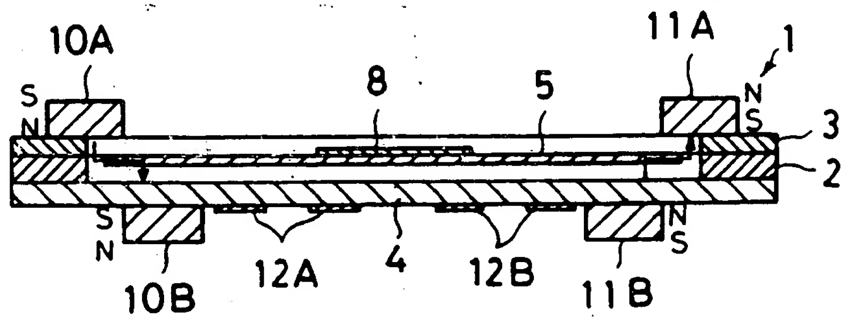


FIG.33



BNSDOCID: <EP___0774681A1_I_>

FIG.34

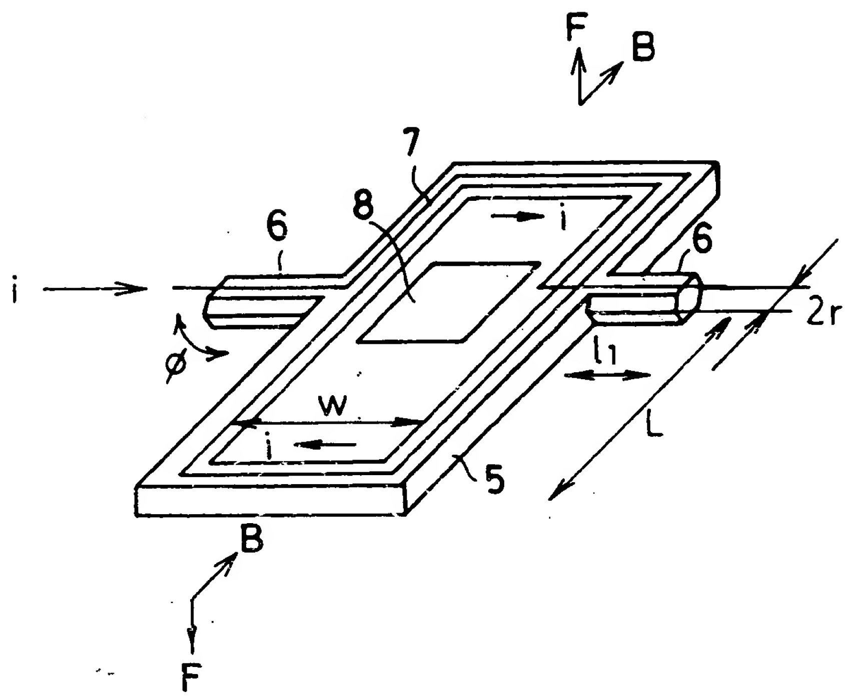
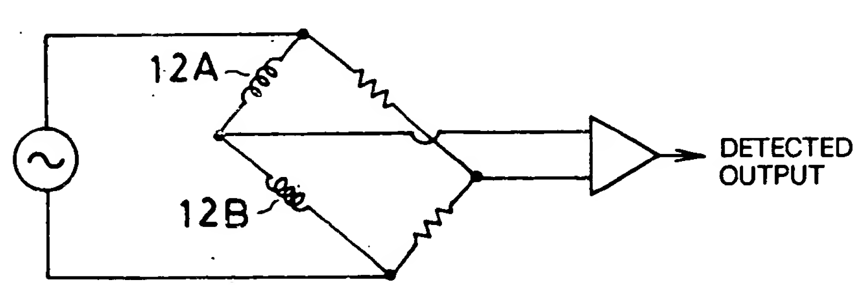
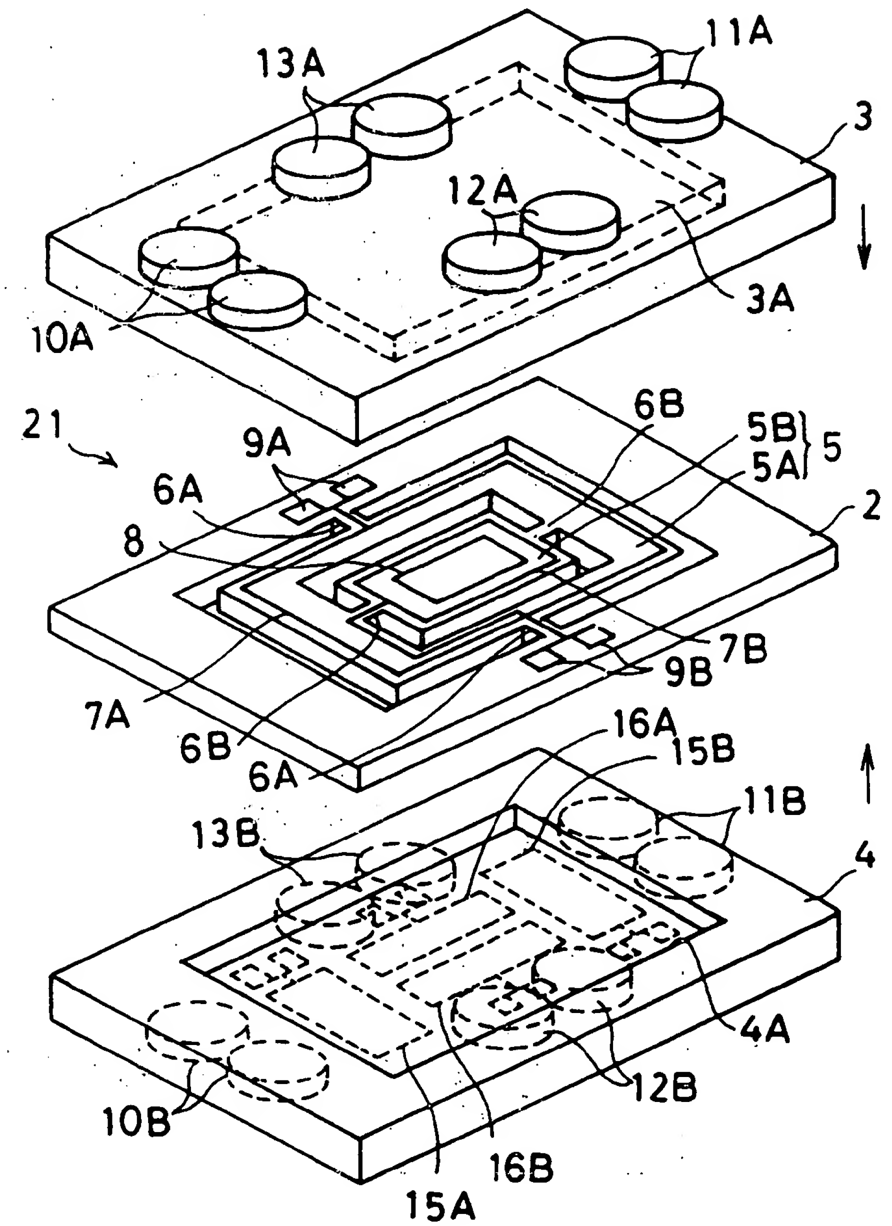


FIG.35



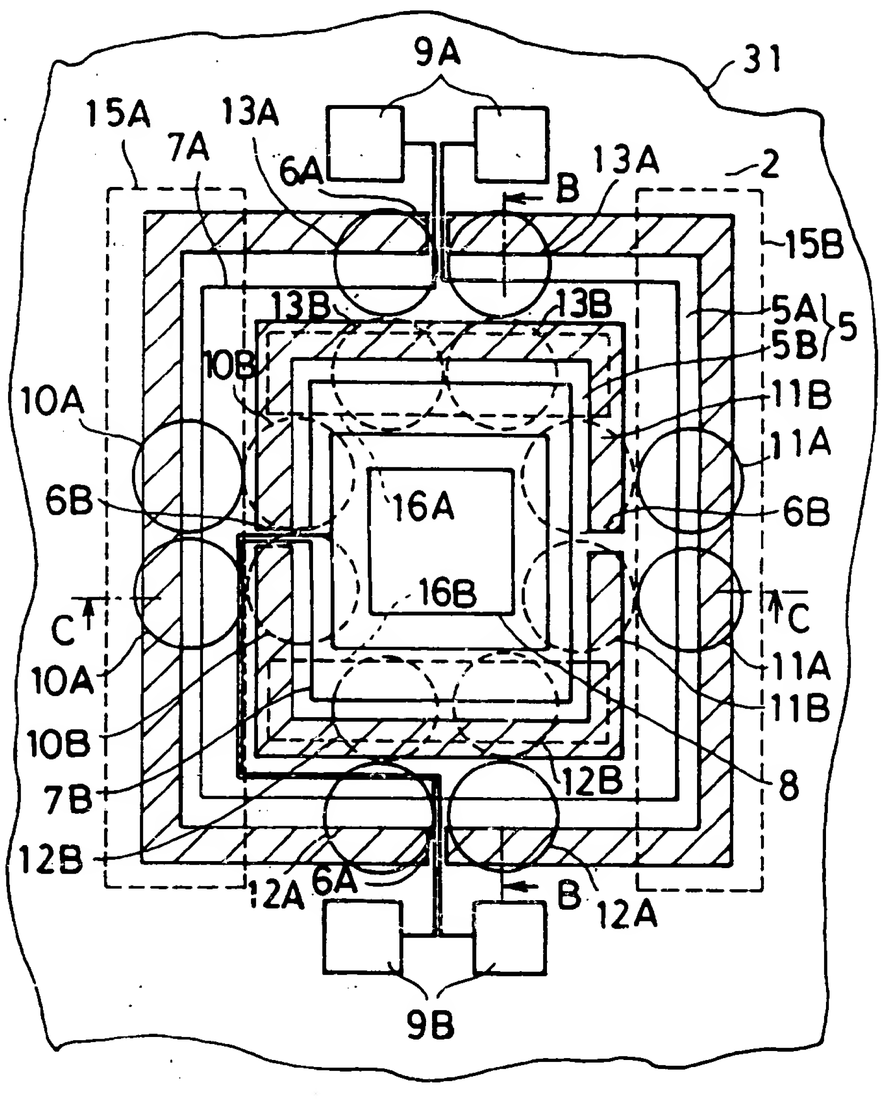
BNSDOCID: <EP___0774681A1_I_>

FIG.36



BNSDOCID: <EP___0774681A1_I_>

FIG.37



BNSDOCID: <EP___0774681A1_I_>

FIG.38

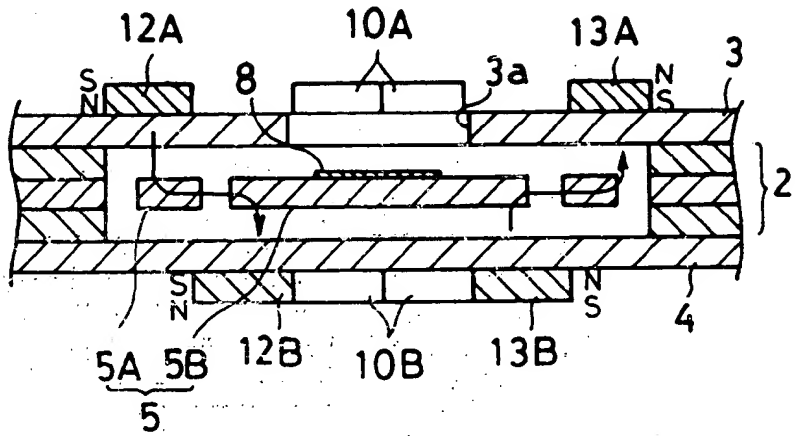
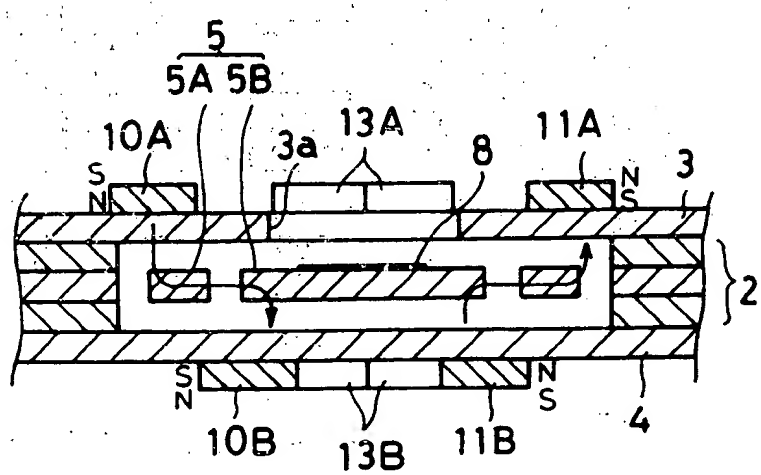


FIG.39



BNSDOCID: <EP___0774681A1_I_>

INTERNATIONAL SEARCH REPORT

International application No. PCT/JP96/01520

A. CLASSIFICATION OF SUBJECT MATTER

Int. Cl[6] G02B26/10

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

Int. Cl[6] G02B26/10, H02K33/18

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Jitsuyo Shinan Koho 1926 - 1995
Kokai Jitsuyo Shinan Koho 1971 - 1995

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
	JP, 60-107017, A (Hitachi, Ltd.), June 12, 1985 (12. 06. 85),	
A	Page 2, upper right column, line 8 to lower left column, line 3	1-5, 12-20
Y		6 - 11
A	Page 3, upper right column, line 7 to lower left column, line 18	3-5, 19-20
Y	Page 4, upper right column, lines 10 to 11; Fig. 5	6 - 11
A	Page 2, lower right column, lines 10 to 17 (Family: none)	16
	JP, 7-27989, A (Fuji Electric Co., Ltd.), January 31, 1995 (31. 01. 95),	
A	Page 3, left column, lines 8 to 25	1-5, 12-20
Y		6 - 11
A	Microfilm of the specification and drwings annexed to the written application of Japanese Utility Model Application No. 120110/1989 (Laid-open No. 58613/1991) (Yokogawa Electric Corp.),	1 - 20

[X] Further documents are listed in the continuation of Box C. [ ] See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance
"E" earlier document but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
September 3, 1996 (03. 09. 96)	September 10, 1996 (10. 09. 96)
Name and mailing address of the ISA/ Japanese Patent Office	Authorized officer
Facsimile No.	Telephone No.

Form PCT/ISA/210 (second sheet) (July 1992)

BNSDOCID: <EP___0774681A1_I_>

INTERNATIONAL SEARCH REPORT

International application No.
PCT/JP96/01520

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
	June 7, 1991 (07. 06. 91), Page 4, line 5 to page 5, line 7 (Family: none)	
Y	JP, 4-211217, A (Fuji Electric Co., Ltd.), August 3, 1992 (03. 08. 92), Page 3, right column, lines 12 to 26; Fig. 1 (Family: none)	8

Form PCT/ISA/210 (continuation of second sheet) (July 1992)

BNSDOCID: <EP___0774681A1_I_>

This Page is Inserted by IFW Indexing and Scanning Operations and is not part of the Official Record

BEST AVAILABLE IMAGES

Defective images within this document are accurate representations of the original documents submitted by the applicant.

Defects in the images include but are not limited to the items checked:

- ☒ BLACK BORDERS
- ☒ IMAGE CUT OFF AT TOP, BOTTOM OR SIDES
- ☒ FADED TEXT OR DRAWING
- ☐ BLURRED OR ILLEGIBLE TEXT OR DRAWING
- ☐ SKEWED/SLANTED IMAGES
- ☒ COLOR OR BLACK AND WHITE PHOTOGRAPHS
- ☐ GRAY SCALE DOCUMENTS
- ☐ LINES OR MARKS ON ORIGINAL DOCUMENT
- ☐ REFERENCE(S) OR EXHIBIT(S) SUBMITTED ARE POOR QUALITY
- ☐ OTHER: ______________________

IMAGES ARE BEST AVAILABLE COPY.
As rescanning these documents will not correct the image problems checked, please do not report these problems to the IFW Image Problem Mailbox.

This Page Blank (uspto)